Experimental Investigation of Pressure Drop Hysteresis in a Cocurrent Gas–Liquid Upflow Packed Bed

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Abstract: Extensive experimental work on hysteresis in a cocurrent gas–liquid upflow packed bed was carried out with three kinds of packings and the air–water system. However, only when packed with small glass beads (ϕ1.4 mm) was the bed pressure drop hysteresis observed. Two more liquids with different liquid properties were employed to further examine the influence of parameters on pressure drop hysteresis. The similarity of pressure drop hysteresis in packed beds was concluded in combination of experimental evidence reported in literature.

Key words: gas/liquid/solid packed column; cocurrent upflow; pressure drop hysteresis; experimental investigation

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1 INTRODUCTION

A cocurrent upflow fixed bed, in which gas and liquid flow upward, is normally used as unit operation equipment in chemical industrial processes. However, the underlying mechanisms of gas–liquid two-phase flow through packed beds are not well understood. For example, wide scattering among experimental data and correlations from different authors for pressure drop across a packed section is not well clarified yet. On the other hand, much insight into the hydrodynamic multiplicity and flow nonuniformity of the trickle-bed has been achieved[1]. Experimental results suggest that hysteresis originates from nonuniformity of radial liquid distribution and multiplicity of hydrodynamic states for gas–liquid flow over stacked small solid particles[2,3]. Similar hysteresis was also reported for a countercurrent fixed bed in which gas flows upward and liquid downward[4]. On the above basis, it may be inferred that similar hysteresis should exist due to nonuniformity of gas–liquid flow in a cocurrent upflow fixed bed, but to the authors' knowledge the hysteresis under this mode of operation was never reported so far except Goto et al.[5]. But their studies were mainly confined to gas(air)–liquid(propylene glycol aqueous solutions) upflow and downflow modes in the bed packed with small glass beads (d_p=0.46, 0.92, 1.83 mm) by changing gas flow rates at constant liquid flow rate. The main objective of this work is to present more experimental data on pressure drop hysteresis, and the pressure drop hysteresis in beds packed with small particles was confirmed in our experiments.

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2 EXPERIMENTAL

The experimental fixed bed was made of plexiglass, 70 mm I.D. with a 1280 mm high packed section, and a gas–liquid distributor was installed at the bottom [Figs.1(a), (b), (c)]. The bed was operated under ambient pressure and temperature. The flow rates of liquid and air were measured with rotameters, and the pressure drop of the fixed bed was measured with a U-type manometer. The air was supplied from an air compressor, and the tap water was circulated through the bed with a subsystem of a pump and a storage tank.

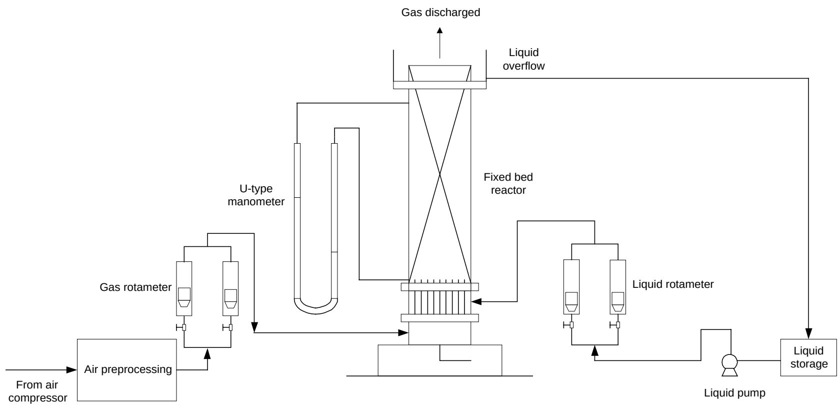

Fig.1 (a) Diagram of experimental apparatus

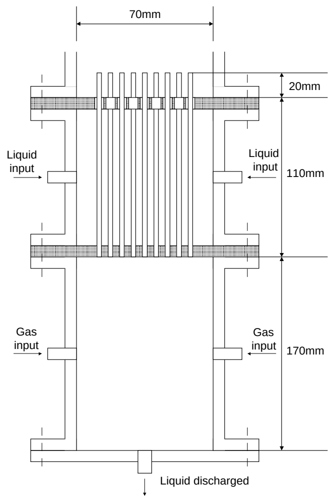

Fig.1 (b) Gas–liquid distributor

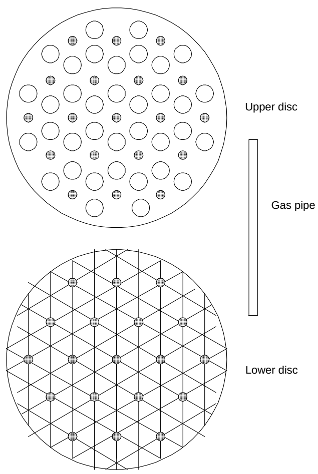

Fig.1 (c) Components of gas–liquid distributor

The packed bed was initially filled with liquid, and the liquid and gas flow rates were then both increased to a high level and the operation was maintained for 15 min to ensure complete wetting of packings. After that, both the gas and liquid were shut off to make the liquid drain off naturally. Twenty minutes later, either liquid or gas flow rate was set at the desired level, and the second fluid, gas or liquid, was introduced to the bed. Its flow rate was increased gradually by steps until a predetermined maximum was reached. Thereafter, the flow rate of the second fluid was decreased until it reverted to the former minimum.

Physical properties of the solid packings and the liquids are given in Tables 1 and 2. The superficial mass flow rate, G, of air was in the range from 1.7×10^{-2} to 7.0×10^{-2} kg/(m^2·s), and the liquid flow rate, L, from 0 to 4.32 kg/(m^2·s).

Table 1 Properties of packings used in experiments

Packings	Shape	Size (mm)	Particle porosity
Ceramic raschig	Cylindrical	10×10×1.5	Porous
Glass bead	Spherical	3.5 (mean diameter)	Nonporous
Glass bead	Spherical	1.4 (mean diameter)	Nonporous

Table 2 Properties of liquids used

Liquid phase	Density (kg/m^3)	Viscosity (Pa·s)	Surface tension (N/m)	Foaming behavior
Water	998.2	1.002×10^{-3}	72.8×10^{-3}	Nonfoaming
Water+0.2%CMC	998.2	2.004×10^{-3}	72.8×10^{-3}	Foaming
Water+0.038%$C_{12}H_{25}SO_3Na$	998.2	1.002×10^{-3}	57.0×10^{-3}	Highly foaming

3 RESULTS AND DISCUSSION

Experimental results show that pressure drop hysteresis can be influenced by many factors. From our experiment, it is found that the smaller the particle size, the stronger the hysteresis. For the bed packed with 10 mm×10 mm×1.5 mm ceramic raschig rings or 3.5 mm glass beads, the hysteresis loop of pressure drop is hardly discernible. Only for ϕ1.4 mm glass beads was the pressure drop hysteresis observed in experiments (Fig.2).

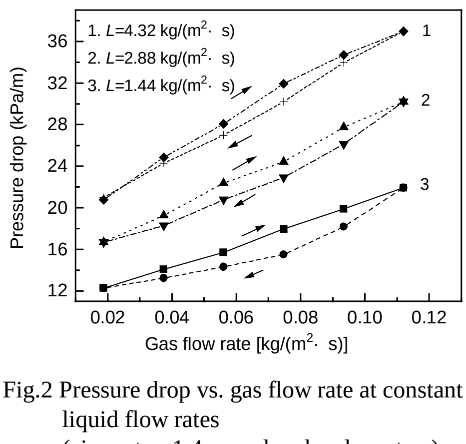

Fig.2 Pressure drop vs. gas flow rate at constant liquid flow rates (air–water–1.4 mm glass beads system)

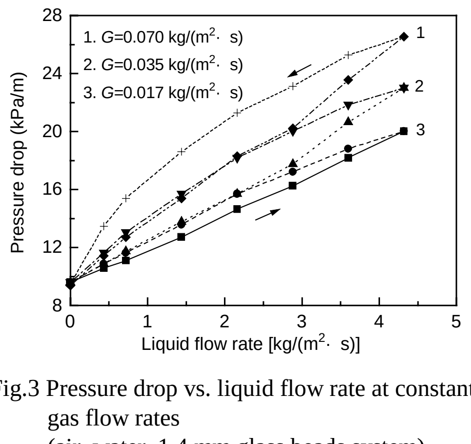

Fig.3 Pressure drop vs. liquid flow rate at constant gas flow rates (air–water–1.4 mm glass beads system)

Among all the influencing factors, it is observed that the liquid flow rate presents the most pronounced effect on hysteresis (as shown in Fig.2). The effect of the gas flow rate on pressure drop hysteresis is shown in Fig.3. Comparison of the three loops in Figs.2 and 3 shows that the greater the gas or liquid flow rate, the stronger the hysteresis. However, the G-increasing branch is the

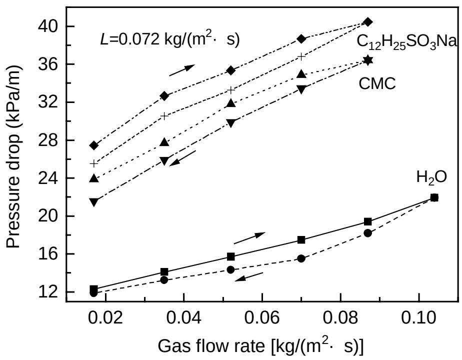

Fig.4 Pressure drop vs. gas flow rate at constant liquid flow rate under different liquid properties (air–1.4 mm glass beads system)

upper one with higher pressure drop in Fig.2, but contrarily the *L*-increasing path corresponds to the lower branch with lower pressure drop in Fig.3.

Figure 4 shows the influence of liquid properties on hysteresis loop of pressure drop. As the viscosity of the liquid phase increases, the pressure drop increases as well, and the hysteresis becomes a little stronger. The similar phenomenon appears as the surface tension of the liquid phase decreases, as can be seen in Fig.4. Higher level of pressure drop is thought due to that low surface tension allows more and smaller bubbles, that in turn creates larger flow resistance to nonfoaming gas–liquid flow. It is also noticed that flooding can be reached at a relatively low gas and liquid flow rates when the surface tension of the liquid phase decreases (Fig.4).

By comparing the experimental results in this work with those in former reports on other operation modes, we can confidently draw the following conclusion. The hysteresis of pressure drop under the three operation modes (gas–liquid cocurrent downflow[4], gas–liquid cocurrent upflow and gas–liquid countercurrent flow[6]) is similar, although the value of the pressure drop of the bed varies in different ranges.

4 CONCLUSION

Experimental results show that in a cocurrent upflow packed bed with small packings, gas and liquid flow rates, physical properties of the liquid influence its hysteretic behavior in pressure drop. The liquid flow rate is ranked the most pronounced factor of influence. The similarity of pressure drop hysteresis behavior of packed beds can be recognized in view of experimental evidence reported in literature.

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