Chemical Engineering Science 143 (2016) 206–215

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

# Hydrodynamics and pressure loss of concurrent gas–liquid downward flow through sieve plate packing

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## HIGHLIGHTS

- Four flow patterns (trickling, continuous, semi- and perfect-dispersed) were found.
- Pulsing flow regime was observed and analyzed, and the flow maps were presented.
- Mechanism of liquid dispersion and its effect on flow resistance were described.
- New correlations for the pressure drop of gas–liquid two phase flow were developed.

## ARTICLE INFO

*Article history:*
Received 15 September 2015
Received in revised form
14 December 2015
Accepted 5 January 2016
Available online 12 January 2016

*Keywords:*
Sieve plate packing
Gas–liquid concurrent downflow
Flow patterns
Pulsing flow
Pressure loss

## ABSTRACT

Gas–liquid concurrent downward flow through a new structured packing was investigated by experiment systematically. The experimental packing consisted of 21 sieve plates. Each plate was 190 mm × 190 mm in side length and 1 mm in thickness. Three sets of packing with different sizes of sieve holes were tested. During experiment, four flow states have been observed, i.e., the trickling flow at low gas and liquid flux, the continuous flow at low gas but high liquid flux, the semi-dispersed flow at high gas flux and the completely dispersed flow as gas flux increases further. Another important phenomenon observed is the occurrence of pulsing flow, i.e., in some range of gas and liquid flow fluxes, both two phases will no longer flow smoothly through the sieve plates but flow downward in pulse regularly. Through extensive experiment, the rough boundaries for flow regime transition were obtained. Then, the pressure losses of gas flow and gas–liquid two phase flow in non-pulsing flow regime were systematically measured. The analysis for pressure differences measured at different locations show that for a given packing, the pressure loss through each plate is nearly the same. Its magnitude depends on the gas and liquid flow rates. The comparisons between pressure losses of different packings indicate that the pressure loss is associated with the hole diameter, hole pitch, free area ratio of sieve plate and the mounting distance between two adjacent plates. Finally, considering these factors, the correlations for pressure drops were developed, which approximates the experimental values with an average deviation less than 10%.



## 1. Introduction

Packed columns are widely used as separation equipment for many years and numerous kinds of packing (both random and structured) have been developed. Of the flow modes identified in packed columns, the countercurrent and concurrent flow are most commonly used in the operation of commercial separation units. Nowadays, a new structured packing consisting of multiple sieve plates has been developed in packed columns operated with gas–liquid concurrent downward flow mode, e.g., the gas stripper in nuclear plants. This new packing with concurrent flow can also be preferred in a wide range of other industrial situations, such as chemical, petrochemical and biochemical industries, etc, especially for mass transfer process when there is no significant difference in the mean concentration driving force offered by two modes (Beg et al., 1996). In such a condition, this new packing with concurrent mode has some marked advantages in two aspects. The first is in the excellent hydrodynamic performance as compared with countercurrent mode, i.e., high throughputs, relatively low pressure loss and absence of flooding (Beg et al., 1996; Saroha and Khera, 2006; Babu et al., 2006; He et al., 2012), and the second is in the simple geometry of the sieve plate packing for manufacture and installment.

However, the design of this new structured packed column still relies on experience or simulation so far and the design result is dubious. To provide reliable guidelines for the design, the understanding to the hydrodynamic behaviors of gas–liquid flow in this new packing is badly needed. At present, most of the relevant

http://dx.doi.org/10.1016/j.ces.2016.01.005
0009-2509/

studies about concurrent flow are focused on random-packed columns, for example, those of Hutton and Leung (1974), Rao and Drinkengurg (1985), Benkrid et al. (1997), Nemec et al. (2001) and Babu et al. (2006) for hydrodynamics, Shende and Sharma (1974) and Mahajani and Sharma (1980) for mass transfer, and Taulamet et al. (2014) for heat transfer. A few previous studies are on structured packed columns, for example, those of Raynal et al. (2004) for metal corrugated sheet structured packing and Schildhauer et al. (2012) for foams and knitted wire packing. Whether for random or structured packing, knowing the hydrodynamic performance is the basis for the investigation of mass or heat transfer. Although those previous efforts have made some contributions to understand the hydrodynamic performance of gas–liquid concurrent flow in packed columns, a lot of research work is still needed to design this new kind of columns precisely and to develop more efficient sieve plate packing.

The aim of the present study is to investigate the flow mechanism and interaction between gas and liquid when they flow concurrently downward through the sieve plate packing, as well as the effect of packing structures, based on systematical experiments, and then to develop practical correlations for the calculation of pressure loss accordingly, so that the guidelines can be provided for the hydrodynamic design and the practical operation of commercial columns.

## 2. Experimental apparatus and process

The experimental arrangement is shown in Fig. 1. The experimental column consists of a sieve plate packing and a rectangular Perspex shell with dimensions of 200 mm × 200 mm × 600 mm, so the flow development in the packing can be observed visually and recorded by a camera. The packing is composed by 21 pieces of stainless steel square plate with 190 mm × 190 mm in side length and 1mm in thickness as shown in Fig. 2. Three sets of packing are tested and their geometrical parameters, as listed in Table 1, are designed by reference to those of commercial unit.

Four pressure taps are amounted along the height of the test packings to measure the pressure losses of gas–liquid flow from the top plate to the 7th, the 14th and the 21st plate, respectively, by three U-tube manometers. The minimum scale of U-tube manometer is 1 $mmH_2O$. In order to insure the precision, the pressure loss through 21 plates is averaged as the pressure loss of one plate. The range of the measured pressure difference in the experiment is from 4 to 470 $mmH_2O$, and the mean error for manometer readings is about 0.84%.

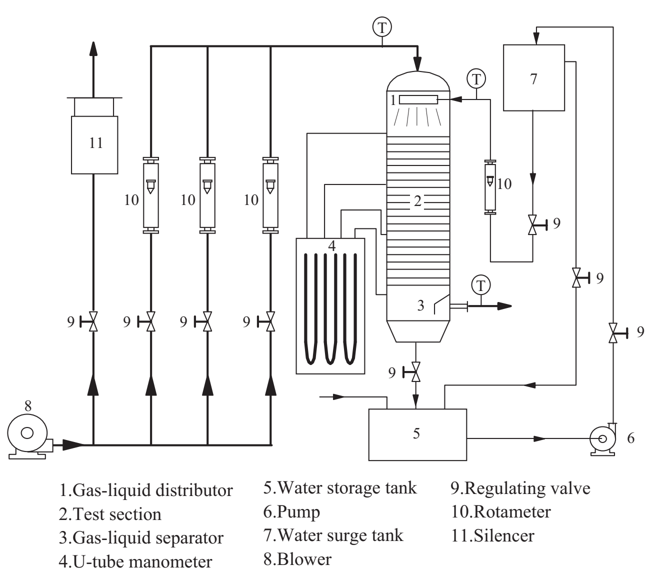


**Fig. 1.** Sketch of experimental setup and air–water flow loop.

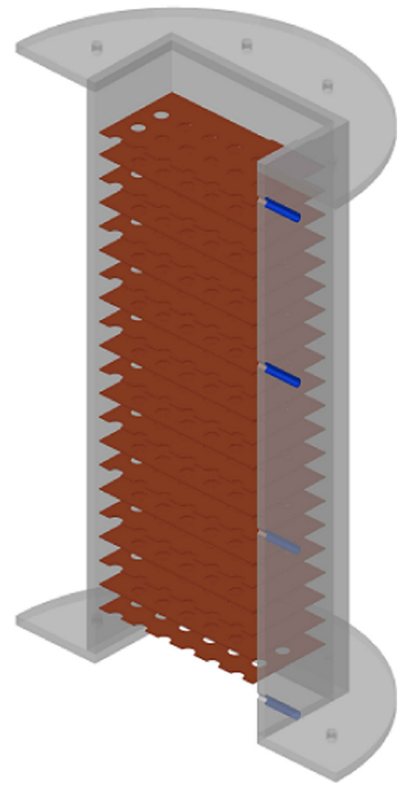

**Fig. 2.** Packing structure.

All tests were carried out by using air and water at room temperature (about 20 °C) and common pressure (1 atm). The range of air flow rate for pure gas phase experiment was 20–250 $m^3$/h. During two phase experiment, the range of air flow rate for packing A was 20–230 $m^3$/h while the range of air flow rate for both packing B and packing C was 20–210 $m^3$/h. The range of water flow rate for each test packing was 0.4–1.6 $m^3$/h. The minimum scale of gas flow-meter is 2 $m^3$/h and in the range of gas flowrate tested, the mean error for gas flow-meter readings is about 1.5%. The minimum scale of liquid flow-meter is 40 L/h and in the range of liquid flowrate tested, the mean error for liquid flow-meter readings is about 4%.

In the experiment, two phases flow concurrently downward through the test packing. Air was sent into the top of the column by a blower and its flow rate was controlled by regulating valves and monitored by rotameters. Water was sent to the liquid distributor mounted at the top of the column under the static pressure provided by an overhead surge tank, and then flowed downward through the test packing by gravity.

## 3. Experimental result and discussion

### 3.1. Flow state of gas/liquid through the packing

For concurrent downward flow of gas and liquid through the sieve plate packing, four typical states are observed, i.e., liquid trickling, continuous flow, semi-dispersed flow and completely dispersed flow. Experiment indicates that the occurrence of these four states depends on the magnitude of gas and liquid flux through the plate hole, the interaction between two phases, and the interfacial effect between liquid and plate.