Powder Technology 260 (2014) 27–35

Contents lists available at ScienceDirect

Powder Technology

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

Flow patterns and transitions in a rectangular three-phase bubble column

Weiling Li, Wenqi Zhong *, Baosheng Jin, Yong Lu, Tingting He

Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China

ARTICLE INFO

Article history:
Received 5 December 2013
Received in revised form 19 February 2014
Accepted 1 April 2014
Available online 12 April 2014

Keywords:
Flow pattern
Flow regime transition
Gas–liquid–solid flow
Particle effect
Three-phase bubble column

ABSTRACT

The flow patterns and transitions in a rectangular gas–liquid–solid three-phase bubble column were studied. The influence of solid volume fraction, particle size and particle density on the flow regime transitions of the three-phase bubble column was investigated experimentally. Experiments were carried out for solid volume fraction $V_s = 0.03–0.3$, average particle size $d_p = 48$ μm–270 μm, particle density $\rho_p = 2500$ kg/m^3–4800 kg/m^3, and superficial gas velocity $U_g = 0.007$ m/s–0.7 m/s in a rectangular bubble column measured 0.8 m tall, 0.1 m long and 0.01 m wide. Four distinct flow patterns and three transition points were observed in this experimental system, and the four flow regimes were discrete bubble regime, transition regime, bubble coalescence regime and strong turbulent regime, which were determined on the basis of criteria as well as schematic diagrams and typical flow pattern images obtained from a high-resolution digital charge couple device (CCD) camera. Typical flow patterns maps were plotted for illustrating flow regime transitions under different particle conditions. It was found out that particle volume fraction and particle density had an effect on the flow pattern transitions; when increasing the values of particle volume fraction and the particle density respectively, the values of the flow regime transition points all decreased. Particle size had a little effect on flow regime transition points when the particle size shifted in the range of 48 μm to 150 μm; when particle size was larger than 150 μm and increased to 270 μm, the operation ranges of the transition regime and the bubble coalescence regime decreased.

1. Introduction

Gas–liquid–solid three-phase bubble columns have been widely utilized in chemical, petrochemical, energy conversion, biochemical and environmental processes [1–5], such as direct coal liquefaction, Fischer–Tropsch (FT) synthesis, CO_2 removal from flue gases in a bubble column [6], heavy oil hydrocracking using catalyst [7], and sodium bicarbonate production [8]. However, there are still some difficulties on the bubble column scale-up technology for industry utilization due to the lack of comprehensive knowledge on the flow characteristics. Flow patterns and transition are two of the important hydrodynamic characteristics of the gas–liquid–solid bubble column, and the mass and heat transfer, mixing efficiency, pressure gradient, momentum loss, pipe vibration and reactor volume productivity of these systems all vary greatly with different flow patterns. Hence, flow regime and transition study is an important respect on understanding the flow characteristics of three-phase bubble columns, and it provides fundamental knowledge on bubble column design, optimization, operation and scale-ups.

Flow regime transition is usually influenced by many factors, such as column geometry, gas distributor design, gas flow rate and operating conditions (temperature, pressure and the physical properties of gas, liquid and particle) [9,10]. Numerous studies have investigated flow patterns in bubble columns, some studies were focused on gas–liquid two-phase systems, and some investigated three-phase systems. The shapes of bubble columns mainly included cylindrical and rectangular two types [11]. When the liquid phase operated in batch mode, Shaikh et al. pointed out that four types of flow patterns had been observed, and they are homogeneous (bubbly), heterogeneous (churn-turbulent), slug and annular flow [4]. Three flow regimes with two flow regime transition points have been identified [12–14], and they were homogeneous regime, transition regime, and the heterogeneous regime. Angeles et al. [7] summarized three types of flow regimes in bubble column reactor, viz., homogeneous bubble flow, heterogeneous bubble flow and churn turbulent slug flow regime. Some scholars [10,15] studied two principal flow regimes, homogeneous and heterogeneous regimes in bubble column systems. Nedeltchev et al. [16] studied a bubble column and identified five flow regimes, and they were: a dispersed bubble regime, first and second transition regimes, a coalesced bubble regime consisting of four regions (called 4-region flow) and a coalesced bubble regime consisting of three regions (called 3-region flow). When

* Corresponding author at: School of Energy and Environment, Southeast University, Sipailou 2#, Nanjing 210096, Jiangsu, China. Tel.: +86 25 83794744; fax: +86 25 83795508.

E-mail addresses: weiling.li09@gmail.com (W. Li), wqzhong@seu.edu.cn (W. Zhong), bsjin@seu.edu.cn (B. Jin).

http://dx.doi.org/10.1016/j.powtec.2014.04.002
0032-5910/

the liquid phase and the gas flow were operated in co-current mode, Shiea et al. [17] detected dispersed bubble flow, discrete bubble flow, coalesced bubble flow and slug flow regimes in their experimental bubble column. Most of these researches were conducted in cylindrical bubble columns, and therefore rectangular bubble columns needed more studies. A rectangular bubble column with a width of 200 mm and a depth of 15 mm was utilized to study the turbulence characterization under both homogeneous and heterogeneous regimes [18].

Particle properties influence the flow regime transitions, and some studies have been performed on the particle effect. Mena et al. [15] discussed the solid effect on homogeneous–heterogeneous flow pattern transition in a bubble column, and provided detailed suggestions on the explanation of the dual solid effect observed. Rabha et al. [19] studied the effect of particle size on the intrinsic flow behavior in a slurry bubble column in order to provide reliable guidelines for optimizing catalyst particle size and solid concentration. Gan [20] studied the solid circulation velocities and holdup profiles in a gas–liquid–solid bubble column, and analyzed the effect of the particle addition on the gas–liquid flow and the three-phase flow hydrodynamics in bubble columns [21]. There is still a lack of detailed understanding of the effect of particles on regime transition, such as the particle size and density effect on the flow structure at different operating conditions [22].

The objective of the study was to investigate the flow patterns in a rectangular bubble column through experiments, and to study the effect of the particle volume fraction, particle size and particle density on the flow regime transition points. This paper is structured as follows. Following the introduction, experimental work is described in the second part. Subsequently, four flow patterns and three transition points are detailed in the third part; flow regime maps are analyzed, followed by concluding remarks.

2. Experimental section

A gas–liquid–solid three-phase bubble column experimental system was built, and the schematic diagram of the experimental set-up was sketched in Fig. 1. The experimental system consists of four sections: a gas–liquid–solid three-phase bubble column, an air supply system, a differential pressure signal acquisition system and a digital image acquisition system. The bubble column measured 0.8 m tall, 0.1 m long and 0.01 m wide and was made of transparent, 6-mm-thick Plexiglas. The air supply system consists of an air compressor, pipelines and flowmeters. The differential pressure signal acquisition system includes the diffused silicon pressure transmitters (GB-3000E and GB-3000HK), a data acquisition card (CDAQ-9188), power supply, positive wire, negative wire and data collection software (Labview 2010 Signal Express). The measurement range and measurement accuracy of the diffused silicon pressure transmitters are 0–2.5 kPa and 0.05%, respectively. The digital image acquisition system consists of a high resolution digital CCD camera and a computer for photo collection. The high-speed digital camera used features a high-speed consecutive shooting mode and shoots 16 frames/s in JPEG mode and thus could be used to capture a series of gas–liquid–solid flow structure images. A 1000-W floodlight was used for lighting and to ensure high photograph resolution.

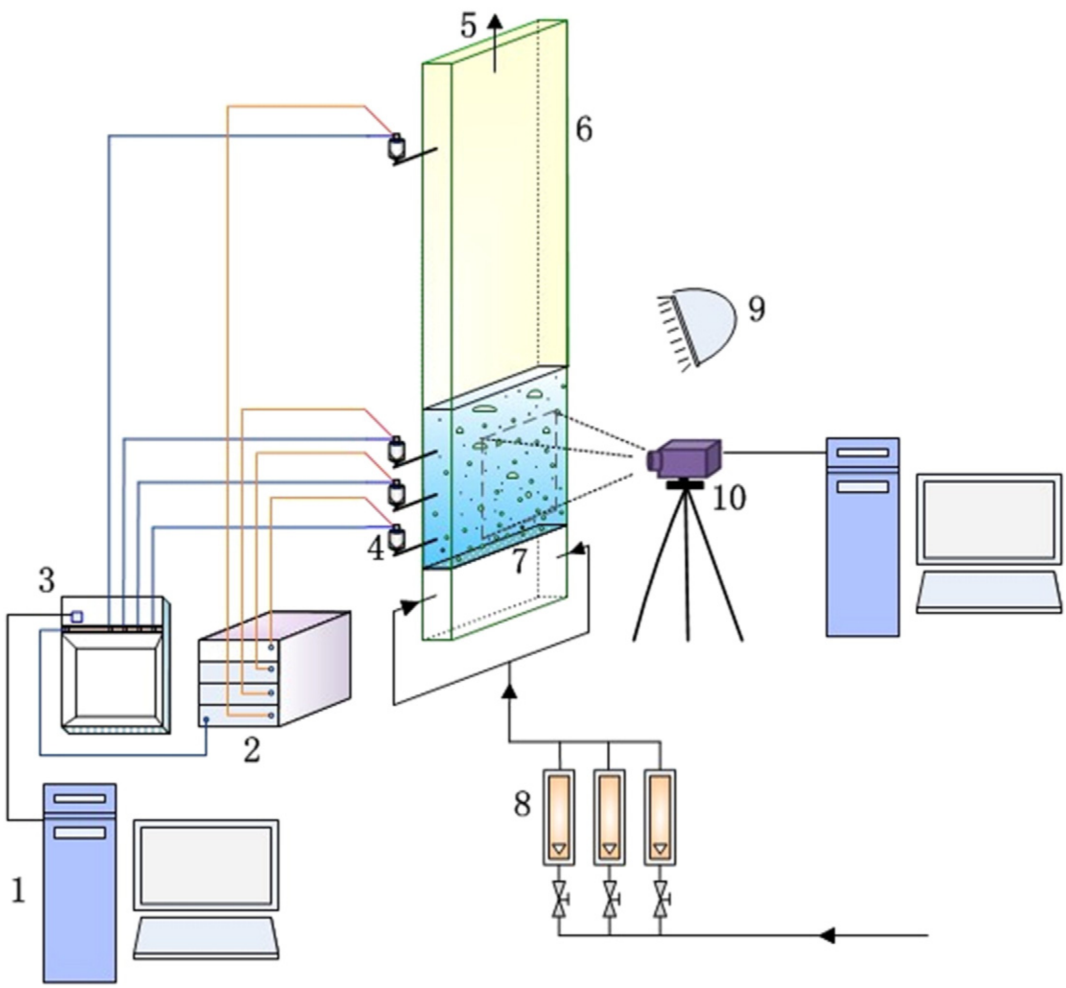

Fig. 1. A schematic diagram of the experimental set-up. 1. Computer; 2. Power supply; 3. Data collector; 4. Differential pressure sensor; 5. Gas outlet; 6. A three-phase bubble column; 7. Metal sintered plate distributor; 8. Flowmeters; 9. Light; 10. CCD camera.