Powder Technology 298 (2016) 119–129

Contents lists available at ScienceDirect

Powder Technology

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

Particle velocity distribution in a flow of gas-solid mixture through a horizontal channel

A. Deshmukh, V. Vasava, A. Patankar, M. Bose *

Department of Energy Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

ARTICLE INFO

Article history:
Received 6 January 2016
Received in revised form 21 April 2016
Accepted 29 April 2016
Available online 15 May 2016

Keywords:
Gas-solid mixture
Channel
PTV
Velocity distribution

ABSTRACT

Detailed velocity distribution as well as the profiles of the mean velocities and volume fraction of the particles in a flow of gas-solid mixture through horizontal channel, are determined using the high speed particle tracking velocimetry, for various combinations of solid mass loading ratios and superficial gas velocities. Spherical glass particles of two different sauter mean diameters are used in the experiment. The smaller particles are better dispersed in the channel than the larger ones. Also, the lower mass loading ratio and higher gas velocity result in more homogeneity in the flow. Particles are observed to accumulate at the bottom of the channel as the mass loading ratio is increased for reduced gas velocities. The distribution of the stream-wise velocity is negatively skewed whereas that of the cross-stream component of the velocity is symmetric. The tail of the distribution is non-Gaussian in nature.

1. Introduction

Gas-solid flows are widely encountered in process industry and is well studied [1,2]. One of the most common examples of particle laden flow in industry is the pneumatic conveying systems, both vertical and horizontal. Earlier studies on the flow of gas-solid mixtures through horizontal or vertical conveying systems can be broadly classified into two categories. In one, the focus was on the macroscopic aspects of the flow such as the pressure fluctuation in the conveying line [3], mapping of different flow regimes and development of various empirical correlations [4,5]. In the second, the focus of the investigation was on the detailed description of the fluid as well as the particle phase dynamics using both experiments [6–8] and numerical simulations [9–12].

In early 1980s, Tsuji and co-workers, for the first time, have determined the profiles of the volume fraction and the velocity of particle phase through horizontal channel [6] and circular pipes [7], using laser Doppler velocimetry. They have also measured the profiles for gas phase velocity and turbulence intensities. They used polymer particles with two different diameters; one is relatively large at 3.4 mm compared to the other at about 0.2 mm. Later, numerical simulations based on the coupled CFD-DEM scheme were performed for the particle laden flow through the channels [11]. The simulation results reported by Lun and Liu [11] are found to be in reasonable agreement with the experimental observations [7]. It is observed, both in experiments and simulations that the volume fraction of the particles is higher near the bottom wall of the channel. Later, in a series of articles, Sommerfeld and his group reported their work on experiments [13] and numerical simulation [14,15] of particle laden flows in a horizontal channel for fine particles with diameters varying between 60 and 625 μm. They have used phase Doppler velocimetry (PDV) to determine the velocity of both particle and fluid phases. They have performed numerical simulations using the algorithms of coupled CFD-DEM method. They have observed that increasing the mass loading ratio shifts the peak of the solid volume fraction from the bottom of the channel toward the centre. They have also investigated the effect of wall roughness on the profile of the solid fraction and concluded that the rough wall contributes to enhance the transverse dispersion and the particle phase volume fraction becomes more uniform across the height of the channel.

In the recent years, Rinoshika and co-workers [16,17] have investigated the flow of gas-solid mixture in a circular pipe using particle image velocimetry (PIV) and determined the profiles of the mean velocity and the solid fraction and the velocity distribution at the centre of a circular pipe with a dune-shaped obstruction [18] for large particles. They have used polyethylene particles with diameters of 2.3 mm and 3.3 mm and determined the velocity profiles of the particles along the radial direction. The have also placed a model dune in the conveying pipe and determined the effect of the obstacle on the mean velocity profile. In addition, they have investigated the fluctuating velocity distribution of the particles and have concluded that the nature is close to a Gaussian distribution function [19].

In the above mentioned articles [6,7,15,18], the authors have determined the velocity profiles and the dispersion of the particles in the channel or pipe in different flow conditions and in some cases offered analysis through simulations; however, to the best of our knowledge, the detailed analysis of the distribution of the particle velocities for

---

* Corresponding author.
E-mail address: manaswita.bose@iitb.ac.in (M. Bose).

http://dx.doi.org/10.1016/j.powtec.2016.04.049
0032-5910/© 2016 Elsevier B.V. All rights reserved.

the particle laden flow in a horizontal channel is yet to be performed. In addition, the effect of the span-wise bounding walls on the nature of the profiles of the particle volume fraction and velocity has not been reported in an explicit manner, e.g., the height to width ratio is 1:4 in the experiments reported in [7], whereas Sommerfeld and co-workers [13–15] maintained the ratio as 1:10 in their experiments. The present work, therefore, has two objectives; first, to investigate the effect of the bounding walls in the span-wise direction on the profiles of mean particle velocity and the solid fraction and the second is to analyze the velocity distribution function of the particles in a conveying system. To that end, an experimental set-up is fabricated with boro-silicate glass test section and particle tracking velocimetry is employed to determine the velocity of individual particles in the system.

2. Material and methodology

2.1. Experimental set-up and method

The experimental set-up consists of transparent boro-silicate glass test section with a cross section of 0.01 m × 0.04 m and a length of 1.5 m, an entry section with a square cross section of 0.04 m × 0.04 m and a length of 0.5 m, a feeder hopper, a compressor (ELGI TS07HN) and an activated carbon based air filter (BIMPEX), as shown in Fig. 1. The micro-filter is installed in the line to remove moisture. The supply line air pressure is maintained at 2 atm gauge with the help of SHAVO, SR02-300-RNMB pressure regulator. The air flow rate is measured by a rotameter (Eureka-PG, 0–13 m^3/h) with a least count of 0.25 m^3/h. The glass particles are fed at the opening of the jet ejector pump, from the feeder hopper mounted vertically above the conveying line. The solid mass flow rate of the particles is controlled in a similar manner described in detail in [20]. Two ball valves are used to control the solid flow rates. One of them is calibrated for the solid flow rate measured at open to atmospheric condition and acts as the particle feed rate controller, and the other one is operated as an on-off valve during experiment. Particles are collected in a bin placed on a load cell (Gill - PEWT DOI with least count of 5 g) at the end of the channel. Fig. 2 shows the snap of the screen at a time instant during the experimental run. The mass flow rate of the particles are obtained by fitting a linear relationship between the mass collected in the bin and time of collection. It is ensured that the mass flow rate is steady during the time the images are captured. All the instruments are calibrated using standard procedures [20].

Spherical glass particles with two different (465 μm and 166 μm) sauter mean diameters (SMD) are used for the experiments. Particles are coloured using permanent maker. To ensure the consistency in poly-dispersity of the feed, the glass particles are conditioned by drying them in oven and sieving them before each run. Solid particles are introduced to the conveying line by opening the on-off valve after the carrier fluid flow is established. Particles are carried to the test section through a converging channel. The location of test section is selected such a way that the point lies beyond the entrance length after the converging section.

Before going into the detailed discussion on the imaging technique employed in this article, a short review of the non-invasive techniques used in the field of multi-phase flow is presented. The detailed investigation of the local volume fraction and the particle velocities has been

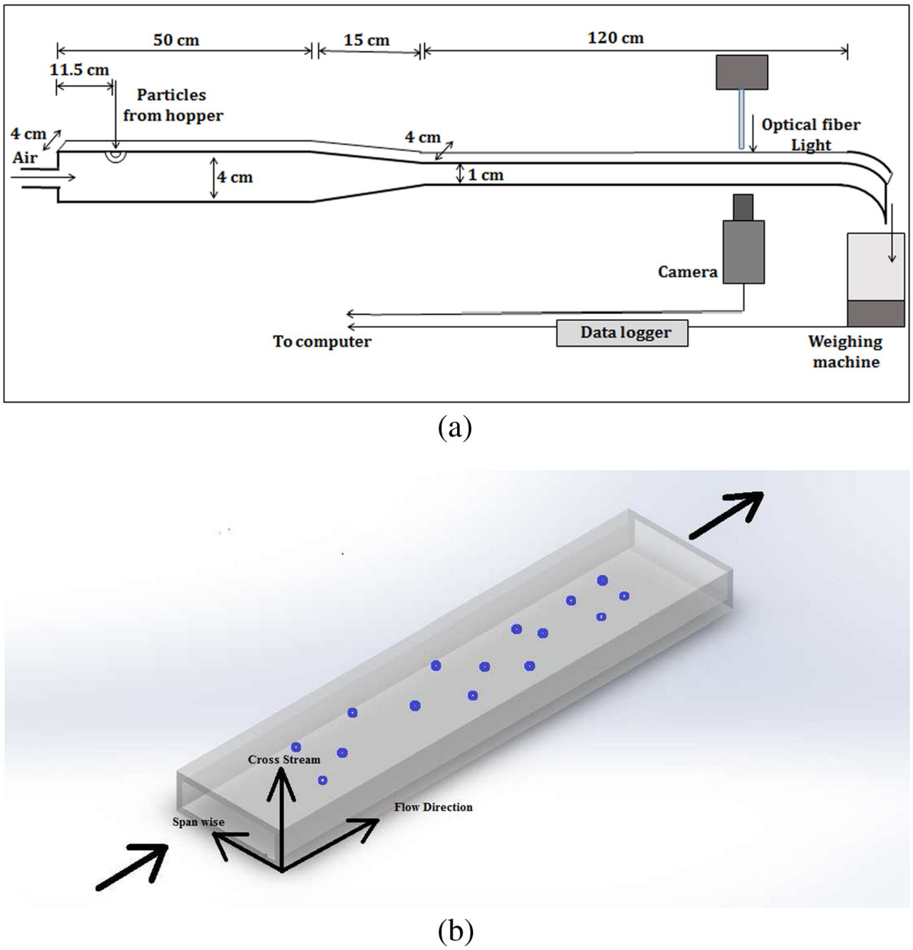

Fig. 1. (a) Schematic of experimental setup, (b) the test section.