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Comparison of particle velocity measurement techniques in a fluidized bed operating in the square-nosed slugging flow regime

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ABSTRACT

The novel "travelling fluidized bed" (TFB), operated under identical conditions, was deployed to compare alternate experimental measurement techniques for the investigation of solid motion in gas-fluidized beds operating in the square-nosed slugging regime. Measurements of particle velocity obtained by radioactive particle tracking (RPT — non-invasive at the Ecole Polytechnique de Montréal), positron emission particle tracking (PEPT — non-invasive at University of Birmingham), optical fibre probes (invasive at UBC) and borescopic high speed particle image velocimetry (invasive at PSRI) are compared for sand particles of mean diameter of 292 μm. Significant differences between the time-average radial profiles of particle velocity are observed in many cases. The results provide valuable insights into the merits and challenges of advanced particle velocity measurement techniques.
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1. Introduction

Among the hydrodynamic features characterizing gas-fluidized beds, particle velocity represents a key parameter which influences heat transfer, gas–solids mixing, erosion, attrition, solids entrainment and particle flux [1].

Various techniques have been investigated for measuring particle velocity in gas-fluidized beds using invasive and non-invasive methods [2]. Invasive techniques based on probing methods represent a good candidate for monitoring plant performance and process optimization in industrial units. However, the degree of flow interference from the probes must be quantified by direct comparison with other techniques employed on the same equipment under identical operating conditions [1,3]. Reliability of non-invasive particle tracking techniques for representing the solid motion should also be investigated. Direct comparison with other techniques represents the most suitable approach.

Except for our group's recent work on voidage and particle velocity measurements [1,3], there have been few attempts to systematically compare different measurement techniques in the past. Werther et al. [4] compared solid velocity measurements obtained by a laser doppler anemometer (LDA) and a single fibre reflection probe in the dilute zone of a circulating fluidized bed riser. These experiments were performed under identical conditions with the same equipment. However, the comparison could not be performed for high-solid-concentration flows since LDA is effective only for dilute suspensions. Panday et al. [5] compared the time-average solid velocity in a CFB obtained by a dual multi-fibre optical probe with data obtained by high-speed particle image velocimetry. Good agreement was observed between the results of these two techniques, but the comparison was limited to one operating condition and few locations.

In this study, four different experimental techniques—radioactive particle tracking (RPT), a non-invasive technique available at the Ecole Polytechnique de Montréal, Positron emission particle tracking (PEPT), a non-invasive technique developed at the University of Birmingham, optical fibre probes, an invasive technique deployed at the University of British Columbia (UBC), and borescopic high-speed particle image velocimetry (PIV), an invasive measurement technique owned and operated by Particulate Solid Research Inc. PSRI were employed to investigate particle vertical motion in the travelling fluidized bed (TFB) facility. This equipment and its auxiliaries were designed and built to assure identical operation in different locations where alternative experimental measurement techniques are available.

In this paper, radial profiles of time-average particle velocity and the probability distribution function of solid velocity obtained by all four techniques are directly compared. Particle velocity results obtained from the TFB with fluid cracking catalyst (FCC) particles are presented

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elsewhere [1]. In this paper, the TFB experiments were performed with a Geldart group B particulate material, sand particles which differed greatly in properties from the group A particles investigated separately [1]. This resulted in a different flow regime and different solid velocity profiles. In particular, for the operating conditions of interest, the sand particles exhibited the square-nosed slugging flow regime typical of Geldart group B particles fluidized at superficial gas velocities (U_g) greater than the minimum slugging velocity (U_{ms}), satisfying the criteria for reaching the slug flow regime [6]. This type of slug flow is regarded as a breakdown of proper fluidization, where high pressures and high interstitial flow rates may break up the dense phase regions releasing pockets of gas, resulting in unstable behaviour. This flow regime, mainly observed in laboratory and pilot scale fluidized beds and of interest for few applications [7,8], provides a useful platform for satisfying the main objective of the study, which is to compare experimental features of a number of the most advanced particle velocity measurement techniques under identical operating conditions. Analysis of the results, focusing on the physical principles underlying each experimental technique and taking into account global flow structures of the multiphase system, provides valuable insights into the reasons for the observed discrepancies.

2. Experimental

The experimental apparatus consists of the easily-disassembled fluidization column, its support structure, basic instrumentation and auxiliary components, all of which travelled with silica sand ($d_{sauter} = 292\ \mu m$, $\rho_p = 2640\ kg/m^3$) particles (as well as FCC powder) to different research laboratories for experimentation using different sophisticated instrumentation. The travelling fluidized bed apparatus, shown schematically in Fig. 1, features a transparent plexiglass column of 0.96 m length × 0.133 m i.d. dense bed section, surmounted by a 1.36 m long × 0.190 m i.d. freeboard section. An internal cyclone with its dipleg terminating in the dense section (0.70 m above the distributor) was employed to capture any entrained particles. Detailed description of the apparatus, and its auxiliary components are given elsewhere [1,9]. Details of the measurement techniques used to determine particle velocity – optical fibre probes, borescopic high-speed PIV, PEPT and RPT – are given elsewhere [1]. Table 1 summarizes the key features of each of these experimental techniques. The optical probe, borescope and RPT solid tracer used in the previous study with FCC powder [1] were used again in this paper for sand.

The minimum fluidization velocity of the sand particles was 0.0796 m/s [9], and all the operating superficial gas velocities investigated were less than U_c (0.72 m/s), the superficial gas velocity corresponding to onset of the turbulent fluidization flow regime, obtained from pressure fluctuation data [3,9], and above U_{ms} (0.16 m/s), the minimum slugging velocity, calculated from the correlation of Stewart and Davidson [6]. As visually observed from X-ray images [10], typical of Geldart B particles [11] in smooth-walled columns of high H/D, the sand particles exhibited square-nosed slugging behaviour, with dense plugs occupying the entire cross-section of the bed moving upwards and solids raining from the bottom through the slug.

The tracer used for the PEPT study with sand differed from that used for FCC powder in order to better match the physical properties of the bulk solids. Sand particles could not be activated enough for the PEPT experiments. Therefore, aluminum oxide, in super-activated base form (gamma-alumina) with properties given in Table 2, was used as the tracer particle. The size and shape of this tracer particle matched well the bulk solid mean diameter, but its density was higher. The RPT tracer particle differed in shape, diameter and density from the sand particles, as shown in Table 2. Considering the sensitivities of the systems when the experiments were performed, the tracer particles employed for

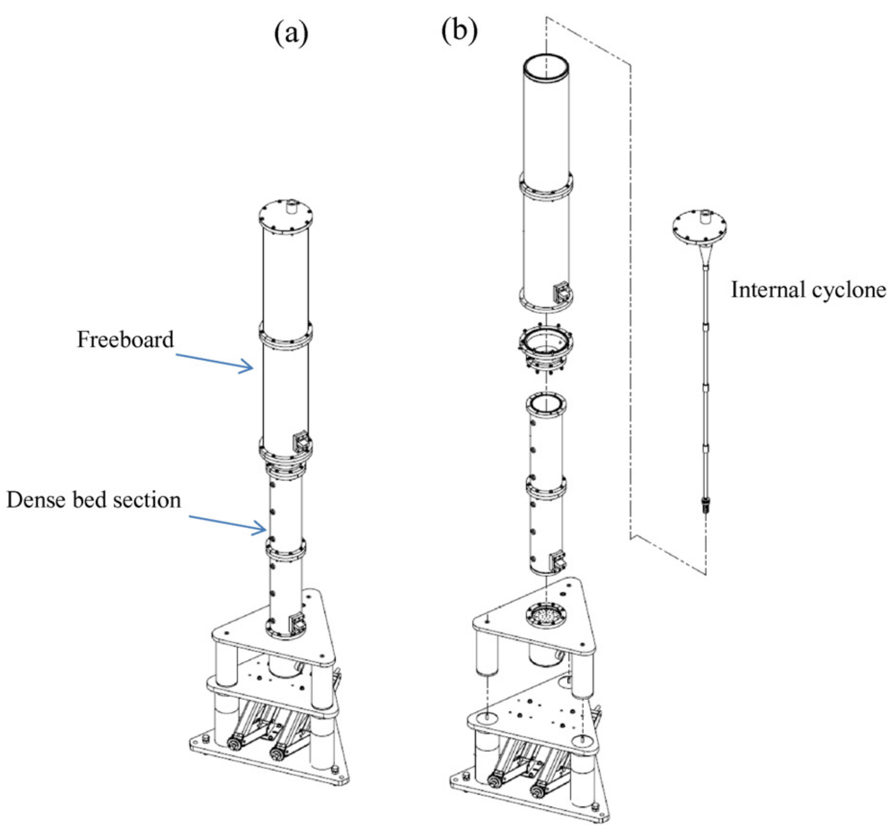

Fig. 1. Schematic diagram of travelling fluidized bed apparatus: a) assembled; b) exploded modular view.
Adapted from Tebianian et al. [1].

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