Powder Technology 270 (2015) 569–574

Contents lists available at ScienceDirect

Powder Technology

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

A comparative analysis of particle tracking in a mixer by discrete element method and positron emission particle tracking

M. Pasha [a], A. Hassanpour [a,*], H. Ahmadian [b], H.S. Tan [c], A. Bayly [c], M. Ghadiri [a]

[a] Institute of Particle Science and Engineering, School of Process, Environmental and Materials Engineering, University of Leeds, Leeds LS2 9JT, UK
[b] P&G Technical Centre Ltd., Newcastle Upon Tyne NE12 9BZ, UK
[c] P&G, Beijing Innovation Centre, Beijing. PR China

ARTICLE INFO

Available online 16 September 2014

Keywords:
Discrete Element Method (DEM)
Positron Emission Particle Tracking (PEPT)
Paddle mixer
Number of tracers

ABSTRACT

Characterisation of particle flow using Positron Emission Particle Tracking (PEPT) is based on tracking the position of a single particle in a dynamic system. Recent developments in PEPT have facilitated tracking multiple particles aiming at improvements in data representation. Nevertheless for systems with a wide residence time distribution and/or dead zone, the conditions for getting representative data which could reflect the bulk behaviour of the powders need to be analysed and specified. In the present work, an attempt is made to simulate PEPT experiments for a paddle mixer using Discrete Element Method (DEM), with a view to investigate the effect of increasing the number of tracers on their time-averaged velocity distribution and whether it can represent the data on whole population of particles. The time averaged velocity distribution of the individual tracer particles (resembling simulated PEPT) is obtained and compared with the time averaged data on entire particle population. The DEM results indicate that for the investigated paddle mixer, it takes 251 s for one tracer to travel adequately in all the active space of the system. The instantaneous tracer velocity fluctuates around the average value obtained for all the particles, suggesting that the average tracer velocity is adequately representative of the average particle velocity in the system. The data of the PEPT experiment with one tracer with those of DEM with one tracer are in good agreement; however, DEM simulation suggests that increasing the number of tracers in the paddle mixer system does not influence the average velocity distribution. Furthermore, the velocity for all particles in the DEM shows a smooth distribution with a peak frequency of the velocity distribution that is lower than PEPT and DEM tracer. When tracking a single tracer in DEM or PEPT, it may not be detected to have zero velocity at any instant of time, whilst the data for all particles show that about 0.3% of particles are stagnant.

1. Introduction

In industries such as detergent, cosmetic, food and pharmaceutical manufacturing, powder mixing is a common process. Optimisation and control of mixing are critically important but very challenging. A key step in optimising the mixing process is to understand the powder kinematic behaviour (flow fields, mixing patterns, etc.) to enable efficient process design and control [1]. However it is difficult to obtain an insight into the internal flow field during mixing processes and to address the kinematic behaviour of powders using experimental approaches, particularly at large scales. Advances in experimental measurements of internal flow based on Positron Emission Particle Tracking (PEPT) have made it possible to get detailed information on the rate of mixing, but are limited to small scales [2,3]. In PEPT, the motion of an irradiated tracer particle is tracked using appropriate sensors, from which the temporal and spatial information about the particle is deduced [4]. A natural question which emerges is to what extent the data from a single particle are representative and how such information could be applicable to larger scales. For this purpose Hassanpour et al. [5] simulated a paddle mixer using the Distinct Element Method (DEM) and compared the results to those of PEPT. A qualitative comparison between the time-averaged velocity profiles of a representative case from PEPT measurements and corresponding DEM simulations showed a good qualitative agreement on the internal flow patterns. In order to make quantitative comparisons, the particle dynamics were analysed in terms of normalised velocity distributions (i.e. magnitude of particle velocity normalised to paddle tip speed). Due to the computational limitations, DEM simulations were carried out for a maximum of 10 s of real time only. Within this short period, the data were insufficient for one single particle relating to comparison with PEPT measurements; therefore the data from all particles in the DEM simulations were used in the calculations. The time-averaged normalised velocity distribution obtained from DEM analysis was compared with that from PEPT measurements for representative process conditions. It was found that the DEM model predicted a smooth distribution of particle velocities whilst the PEPT data showed more scatter or fluctuation in the frequency plot. This difference was attributed to the fact that the PEPT analysis was based on

* Corresponding author. Tel.: +44 113 343 2407; fax: +44 113 343 2405.
E-mail address: a.hassanpour@leeds.ac.uk (A. Hassanpour).

http://dx.doi.org/10.1016/j.powtec.2014.09.007
0032-5910/

data from only one particle, i.e. the tracer, whilst the DEM results were from the velocity profiles of the whole population of particles. Overall there was a reasonable agreement in the velocity distribution, but the comparison was not rigorous.

In PEPT the tracking process is carried out for a few minutes to generate sufficiently accurate time-averaged data. However, the total length of experiment for reliable and statistically representative data is based on trial and error and there is no solid evidence confirming that the tracer could represent the data for all particles. It has recently been shown [6] that using manipulated algorithms, multiple tracers can be used in PEPT; however its effect on providing better representative data for all the particles has yet to be critically evaluated. In the present work, an attempt is made to simulate PEPT experiments for a paddle mixer using DEM, with a view to investigate the effect of increasing the number of tracers on the time-averaged velocity distribution. The velocity information is available for all individual particles in DEM; therefore, the average particle velocity and velocity distribution of the whole population of particles could be compared with those of individual tracers in the simulation. The results of DEM are also compared to those of PEPT experiment using a single tracer.

2. DEM simulation of the paddle mixer

DEM simulations provide dynamic information of transient forces acting on individual particles throughout the simulations, which is otherwise difficult to obtain. The interactions between the constituent particles are based on theories of contact mechanics. More details on the methodology of the DEM and its applications are presented elsewhere [7,8]. The simulations were conducted using EDEM® software provided by DEM Solutions, Edinburgh, UK. The calculation of the contact forces of the particles is based on the Hertz–Mindlin model [9]. The experimental work using PEPT was carried out on dry, free-flowing particles; hence the contact model did not include adhesive term. Due to the limitation of computer power, it is not possible at this stage to simulate the actual number of particles (around 50 millions) within a reasonable time. Therefore, the simulation was carried out with a smaller number but larger particles. In this case particle density is adjusted to maintain a similar momentum exchange between particles as of the real case [10]. In the previous work by Hassanpour et al. [5] it was shown that the steady state average velocity magnitude slightly decreased as the particle size was reduced in the same paddle mixer system. This shows that the average particle velocity is slightly sensitive to the particle size, but the effect is not very significant. Here, the same particle size similar to that used by Hassanpour et al. [5] is used. The geometry of the simulated paddle mixer is the same as the previous work, for which a CAD drawing was imported into the EDEM computer code (Fig. 1).

Table 1
The properties of particles and walls used in DEM simulation.

Property	Particles	Equipment wall
Particle diameter (mm)	4.52	–
Shear modulus (GPa)	0.1	70
Density (kg/m^3)	1000	7800
Poisson's ratio (−)	0.2	0.3

As it can be seen, the mixer consists of two intersected semi-cylinders of the same span and two counter-rotating impellers, each with 10 paddles positioned pair-wise along 5 axial positions. Properties of the particles are also the same as the previous work [5], which can be seen in Tables 1 and 2. Particles were generated randomly at spatial locations above the impellers (the position shown in Fig. 1).

The filling of 60,000 particles was carried out whilst the mixer impellers were stationary similar to previous work [5]. The particles were subjected to gravitational acceleration and gradually settled towards the bottom of the mixer. The simulations were carried out under a constant rotational speed of impellers for 10 min of real time which took three months to complete. For confidentiality reasons it is not possible to disclose the impeller rotational speeds.

3. PEPT experiments

The experimental results of PEPT are taken from the previous work of Hassanpour et al. [5]. In their work, the Positron Emission Particle

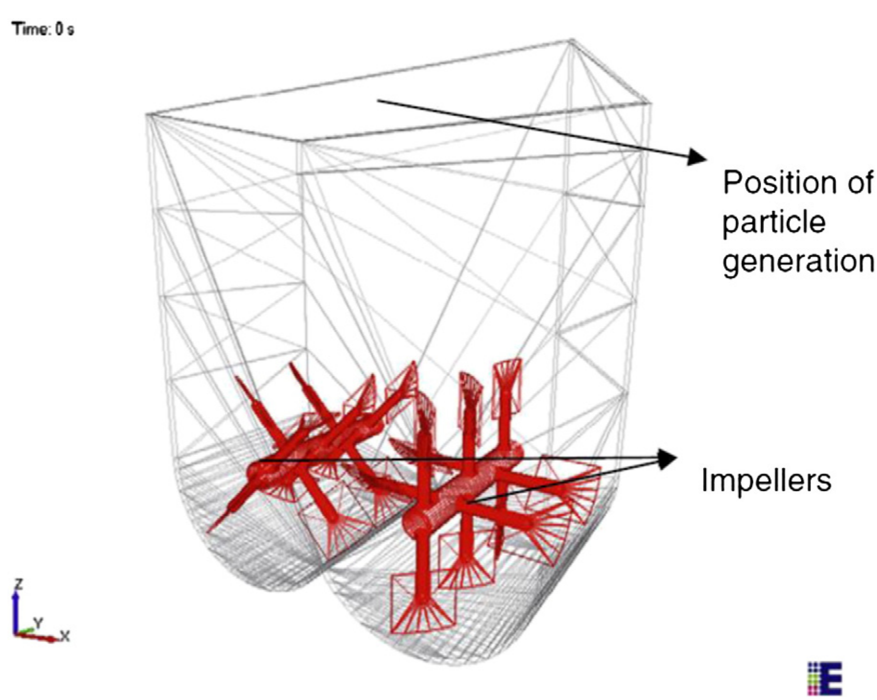

Fig. 1. The imported geometry of the paddle mixer simulated by the DEM.