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Solids circulation and axial dispersion of cohesionless particles in a V-mixer

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Abstract

The motion of mono-sized 3 mm glass beads in a V-mixer was studied using the Positron Emission Particle Tracking (PEPT) technique. A similarity is found between the motion in V-mixers and in rotating drums. In both cases, there is a surface flow regime and a solid body motion regime. Within each arm of the mixer, there is a regular circulation in rotating Lagrangian coordinates, the direction of which changes as the volumetric fill increases. The flow reversal occurs at intermediate fills and is system dependent. It was attributed to the surface flow regime and the freeboard in the arm of the V-mixer. The circulation intensity in the arm was quantified and was found to increase quadratically with increasing rotational speed. It was attributed to the kinetic energies of particles within each arm. The circulation intensity decreases when the fill level increases from 10% fill to 46% fill and a minimum value exists at intermediate fills. The axial dispersion coefficient of the particles in the V-mixer increases linearly as the rotational speed increases from 15 rpm to 60 rpm.

Keywords: V-mixer; Particle mixing; Positron Emission Particle Tracking; Flow reversal

1. Introduction

Particle mixing is an important unit operation in many industries, especially for the manufacture of pharmaceuticals, metallic parts, fertilisers, animal fodder, ceramics and foods. In a typical pharmaceutical manufacturing process, powders are mixed in a mixer and emptied into a silo on a press or encapsulator to form the final dosage form. Therefore, achieving and maintaining homogeneous mixing of powders is of critical importance, especially in formulations involving small amounts of high potency components [1]. The effectiveness of the industrial mixers was therefore deliberately studied (e.g., [2]).

Two main categories of mixers are frequently used: tumbling and vessel-fixed types. Tumbling mixers rotate about a horizontal shaft and include rotating drums, double-cone mixers, V-mixers and many other types. Vessel-fixed types mix particles by use of impellers, rising screws, compressed gas or other devices. The mechanisms of particle mixing have been studied at least since Lacey [3]. Generally, it is asserted that three mechanisms are involved: convection, diffusion and shearing. However, our understanding of particle mixing is still limited compared to that of fluid since the flow patterns have not been fully studied. As a result, the selection of mixers is largely empirical and few design criteria are available.

V-mixers consist of two cylinders of equal length joined together at an angle between 75° and 95°. They are common devices for batch solids mixing in many industries, especially pharmaceutical manufacture, since they are relatively easy to clean. Since the mixing between the two arms is considered to be slow compared to the mixing within each arm, some modifications have been suggested to improve the performance of the mixer: for example using unequal cylinders [4], adding paddles on the rotating shaft

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[5] and introducing a rocking motion in the axial direction to increase flow perturbations [6].

Most of the early work carried out on V-mixers focused on the comparison of the quality of mixing between different kinds of devices [7–11] or different kinds of solids materials [12,13]. Only limited work has been carried out on the influence of the operating conditions (rotational speed, fill level, mixing time). Brone et al. [14] studied the quality of fine (66 μm) powder mixing using an experimental method in which the mixture was fixed in a gel, then sectioned and each section was carefully examined. The rate of mixing was found to increase significantly as the fill percentage was decreased from 60% to 40% of the total vessel volume. Assuming that the mixtures in the two arms are "well-mixed", they proposed a one-parameter model based on the amount of material crossing the plane of symmetry per revolution. The parameter is a function of the physical properties of the powder, the fill level and the rotational speed of the mixer and this approach can adequately predict the mixing rate. However, due to the limits of the experimental technique, the particle motion in the mixer was not fully investigated.

Although particle motion in a V-mixer was studied using particles of two different colours [15–17], the reported flow patterns were schematic drawings in two dimensions. A detailed description of particle motion in the V-mixer is still not available. In this work, particle motion in the V-mixer is studied using the Positron Emission Particle Tracking (PEPT) technique. This technique has been used to study particle motion in rotating drums [18–20]. The current work concerns the details of the particle motion within the arms and is aimed at determining the effect of fill and rotational speed on the motion of the mixture in the V-mixer.

2. Materials and methods

The experimental method used is Positron Emission Particle Tracking (PEPT). PEPT is a non-invasive tracking technique developed at the University of Birmingham, which is modified from the medical Positron Emission Tomography (PET) imaging technique. It works by introducing a single radioactive tracer particle to the system of interest. The location of the tracer particle is monitored as a function of time; provided that a sufficient time interval is studied, the data are representative of the motion of all particles in the equipment. The camera detects the two collinear γ-rays which are produced when a positron emitted from the tracer annihilates with a local electron. The recorded collinear γ-rays are used to reconstruct the location of the tracer particle, and hence the trajectory of the tracer particle and real-time speed can be reconstructed precisely. The maximum field of view is $80\times50\times40$ cm^3 although accurate tracking is impossible near the edges of the field of view and this limited the size of V-mixer studied. More detailed information can be found elsewhere [21,22].

Fig. 1 shows the V-mixer used in the experiments and the relative position of the V-mixer and the two detectors. The mixer shell is made from "Perspex" acrylic and the particles used were spherical glass beads of 3 mm in diameter. Although solids mixing usually involves differently sized powders and particles, it is the trajectories of particles in the V-mixer that are important in this work. In order to select a representative tracer, mono-sized 3 mm particles were used as the bulk and a tracer of the same size and physical properties was used. The operating conditions are summarised in Table 1. The particle size used is obviously very large compared with the size of interest in most mixing operations. The size of pharmaceutical powders is typically in the range of 5 μm to 500 μm. The PEPT technique is able to track particles down to 60 μm in size. Introducing the activity to a 60 μm tracer particle is usually made by ion exchange and the activity is lower compared with that introduced by direct irradiation with the beam from a

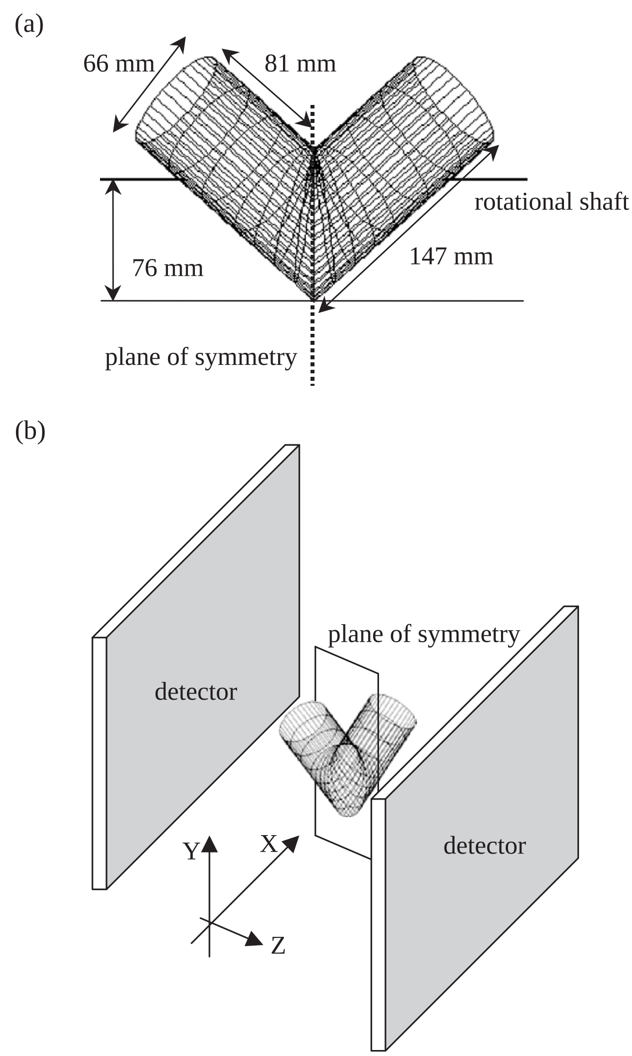

Fig. 1. (a) The geometry of the V-mixer; (b) the schematic drawing of the relative locations of the pair of the detectors and the V-mixer. The plane of symmetry is located at x=288 (mm). The shaft of rotation is located at y=322 (mm) and intersects with the plane of symmetry at z=205 (mm).