CS 2 - 2〔II〕 Granular Flows in a Rotating Cylinder: Non-invasive measurement by MRI

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INTRODUCTION

In chemical industries rotary cylinders have been used for comminuting and mixing grains and powders. Despite their frequent use, studies of these flows have been hindered largely due to the lack of non-invasive experimental techniques to measure flow properties.

Magnetic Resonance Imaging (MRI) techniques for studying flowing fluids have been described previously (1) and we now show preliminary results to demonstrate their application to multiphase flows of discrete materials. The unique characteristics of MRI allow non-invasive determination of concentration and average velocity distributions anywhere in a sample. We present two-dimensional images showing concentration and velocity, free from end effects, of a relatively thin slice perpendicular to the cylinder axis of steady granular flows in a rotating cylinder.

EXPERIMENTAL

A Nuclear Magnetic Resonance (NMR) imager/spectrometer (Nalorac Cryogenics Corp.) with a 1.9 Tesla superconducting magnet (Oxford) having a bore diameter of 31cm was used. Fig.1 shows a schematic view of the entire apparatus.

The acrylic cylinder with a large length-to-diameter ratio (585mm long with an inner diameter of 88mm) was rotated about its axis by a well-regulated electronic motor through a long non magnetic aluminum shaft which is required to keep the motor far from the magnet.

Because MRI is best suited for the study of mobile protons, it is useful only for certain granular materials. In this study we used mustard seeds because they are relatively round, hard, easily accessible, and yield excellent proton NMR signals from their oils. The average diameter of the seeds is 1.4mm, the average density is 1.3 g/cm^3, and the average coefficient of restitution is about 0.56 when they were dry and at room temperature.

The MRI experiment selected a 8mm thick slice, transverse to the cylinder axis, with an inplane resolution of 0.8mm. This is smaller than the average diameter of mustard seeds. The orthogonal components of the velocity, V_x and V_y, were measured in two independent experiments with a total measurement time of approximately 15 minutes. MRI measures average flow properties over this time period within each voxel. The velocity parallel to the flowing layer (Fig. 2) was calculated from these orthogonal measurements.

RESULTS

Figs. 2 and 3 show the profiles of velocity and concentration, respectively, of mustard seeds in a half filled cylinder rotating at 0.51 rev/sec and 0.88 rev/sec. Here the velocity is the component parallel to the flowing layer. The velocity data were smoothed to enhance the signal-to-noise ratio, and the absence of an abrupt velocity transition from non-zero to zero at the interface is because of this smoothing. Velocity profiles show two distinct linear regions, one for the seeds undergoing rigid body rotation and one for the flowing layer. Between those two regions, a transition zone with a nonlinear velocity profile is present. Judging from observation of flows on video tape, this appears to be the region where seeds are interacting through not only colliding but also sliding. The maximum speeds of seeds undergoing rigid body rotation are about 14.1 cm/sec and 24.3 cm/sec at 0.51

rev/sec and 0.88 rev/sec, respectively. The corresponding maximum speeds of the flowing layer are about 56.4 cm/sec and 69.9 cm/sec with respect to the top of the rigid body layer. The concentration profile in the rigid body rotation region is uniform within experimental error, but is lower in the flowing region because of dilation. For the faster flow, the concentration transition from rigid body to flowing layer is sharper than that for the slower flow.

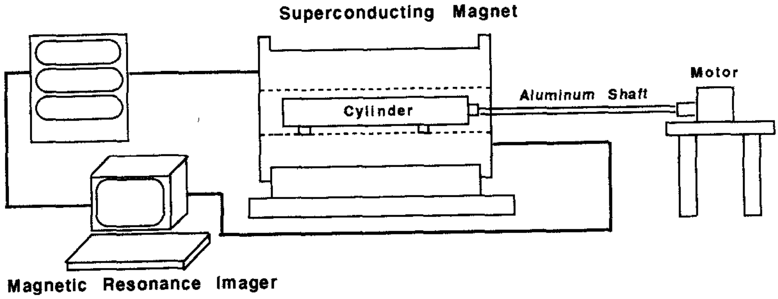
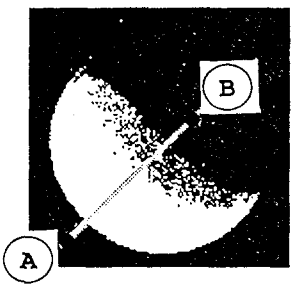
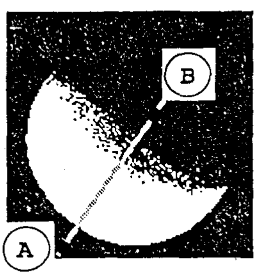


Fig.1. MRI apparatus



0.88 rev/sec.



0.51 rev/sec.

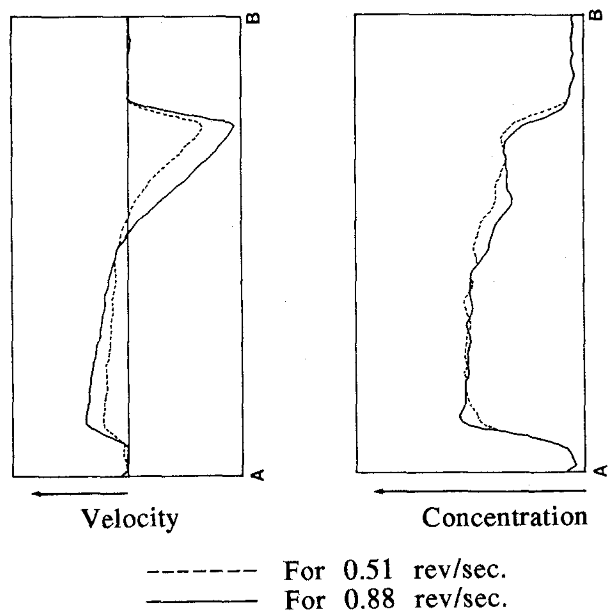


Fig.2. Velocity profiles. Fig.3. Concentration profiles.

REFERENCE

1. Caprihan, A. and Fukushima, E., " Flow Measurements by NMR", Phys. Rep.198,1990, pp.195-235.

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