

Flow Visualization in a Packed Bed Reactor using PIV and Refractive Index Matching

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1. Introduction

A typical packed bed is a column where a fluid is flowing through packed grain-like material. A large part of our natural environment as well a substantial fraction of man-made processes can be represented as a packed bed. One approach to obtain flow velocity fields of interstitial space in a packed bed configuration is the use of the Particle Tracking Velocimetry technique. A difficulty of this method when used in porous media is the need for optical access of the medium. In order to overcome this complexity, the solid particles used as packing material and the fluid flowing through the column can be chosen in such a way that their refractive indices are matched. In this way, the optical accessibility required by the PTV technique can be achieved.

2. Experimental set-up

A vertical column (3cm x 3cm x 35cm) was constructed out of Acrylic and randomly packed with 6mm diameter PMMA beads. The column was connected to a closed loop with a reservoir tank and pump. The flow was controlled by means of a flow valve in the loop between the pump and the column. A flow meter (McMillan 100 series) was connected to the loop to measure the flow rate. The flow loop and reservoir were filled with p-cymene and pumped through the loop. Immersing the reservoir tank in an ice bath provided a constant temperature in the system. The PTV system used a laser as an illumination source. The laser beam was directed to the medium via optical array of mirrors and lenses in order to produce a laser sheet of about 5 cm height, and 1 mm thick in the midplane of the column. The laser sheet impinged perpendicular to the column's axial plane. A high-resolution/high-speed camera (1 K X 1 K pixels, 2000 fps) was placed perpendicular to the laser sheet plane. The camera had an equivalent viewing area of about 3.2 cm x 3.2 cm. This configuration allowed us to measure velocity fields in the X-Y plane with reasonable time resolution.

3. Results

The use of p-cymene allowed PTV measurements to be performed at the center of the packed bed square channel. The results in this investigation showed the velocity distribution at the pore scale level. Various pore geometries were observed at the column's midplane. These geometries elucidate the complexity of the flow paths

along the pore (Figure 2). Vortices were identified in the pores between beads. The average size of the vortices was approximately 2 mm at a $Re_p = 6$. The preliminary results indicate that the amount and size of the vortices increase with the pore size. Vorticity maps were calculated from the obtained velocity fields at the pore level. Higher vorticity zones were identified near the boundary of the packing material.

4. Conclusions

The p-cymene proved to be the most suitable liquid to use in Refractive Index Matching allowing the use of Particle Tracking Velocimetry as a non-intrusive velocity measurement technique in a packed bed. The measured velocity distribution at different pore-geometries in the midplane of the test column showed a relation with the size and geometry of the pore. Identification of vortices and their length scales can help in the understanding of mass and heat transfer parameters. Specifically, in the nuclear pebble bed reactor where information extracted can be used to help understand the turbulent parameters involved in the complex heat transfer phenomena at pore scale.

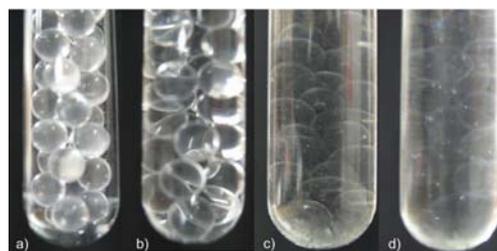


Figure 1. PMMA beads immersed in a) air b) water c) p-cymene d) RI matched sodium iodide solution.

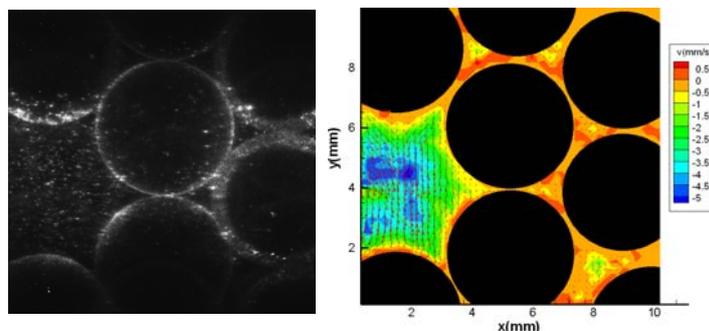


Figure 2. Typical instantaneous a) PIV image and b) velocity contour plot at column's midplane.