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Deposition behaviour of very dense particles in high-concentration slurry flows

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ABSTRACT

Nuclear industry legacy waste, in the form of radioactive sludges and slurries, exist on several nuclear sites across the UK, and its characterisation and disposal represents an ongoing challenge. The mechanisms by which very dense particles are transported in pipes are not well understood.

The aim of this project is to perform fundamental research on dense particles in bi-disperse suspensions, since such suspensions represent a simple analogue for more complex, polydisperse slurries that are typical of legacy waste. Two complementary sets of experiments will be performed – one with a water/glycerol mixture as the carrier fluid, and another with a low-density-particle/water mixture, to both of which a second species of higher density particles will be added – in order that the effect of density differences between species on settling, deposition and turbulence modification behaviour can be investigated.

A new, versatile experimental slurry flow loop has been constructed that will be used alongside an existing flow loop to obtain basic data on the transport and deposition behaviour of dense particles, using both ultrasonic Doppler velocimetry profiling (UDVP) and particle image velocimetry (PIV) methods to characterise the flow and deposition behaviour. Details of the new flow loop are presented; initial mean flow velocity measurements are compared with data in the literature; initial particle characterisation results are also presented.

INTRODUCTION

The UK nuclear industry has in its inventory radioactive legacy waste that currently exists as complex, polydisperse and "polydense" slurries and sludges in a variety of storage vessels. Owing to radioactivity and limited accessibility, this waste has been difficult to characterise, and because it can form solid beds and has been found to leach out of storage vessels, containment and disposal of the legacy waste presents a continuing challenge.

Contained in these slurries are small amounts of very dense, highly radioactive particles. How such particles behave in polydisperse suspensions is not well understood.

AIMS OF THE PROJECT

The aim of this project is to investigate high-concentration, bimodal suspensions containing dense particles in pipes of circular cross-section in order to provide basic data that will aid in the characterisation, transport and disposal of nuclear waste slurries. Bimodal suspensions represent simple analogues for more complex, polydisperse and polydense concentrated slurries and sludges that are typical of nuclear industry legacy waste.

As well as basic slurry flow data – on settling, deposition and resuspension behaviour – it is intended to produce experimental data on more fundamental fluid-dynamical processes such as modification of turbulence by suspended particles (Poelma and Ooms, 2006), and fluid-particle and particle-particle interactions more generally.

MODELS OF SLURRY BEHAVIOUR

Several theoretical and phenomenological models exist that give viscosity-concentration correlations for simple mono- (Mendoza and Santamaria-Holek, 2009), bi- (He and Ekere, 2001) and polydisperse suspensions (Farris, 1968). However, models of the behaviour of more complex polydisperse and polydense slurries are generally phenomenological or empirical rather than predictive and take account only of bulk properties (Matousek, 2005).

A large canon of correlations exist for bulk flow characteristics (Crowe, 2006), but less work has been done to attempt to link the observed behaviour at the microscopic scale (*i.e.* polydispersity, polydensity) to that at the macroscopic (*i.e.* velocities, pressure drop and concentration profiles).

PROPOSED EXPERIMENTS

It is proposed that two sets of complementary experiments be performed, with the following carrier “fluids”:

1. Water + glycerol;
2. Water + low-density particles.

In the first case, the concentration of glycerol will be varied in order to cover a range of viscosities; in the second, the concentration of low-density particles will be varied. The effects of inter-species interactions can thereby be isolated by equating the effective viscosity in each case.

Using expressions given by Cheng (2008) and Mendoza and Santamaría-Holek (2009), the mass concentration, C_m, of glycerol in a glycerol-water mixture that has the same viscosity as a suspension of monodisperse particles of volume concentration ϕ can be found.

The experiments are intended to satisfy a number of criteria:

a. to cover a large range of viscosities and particle concentrations in order to simulate as wide a range of nuclear slurries as possible;
b. to quantify fluid-particle and inter-species interactions by comparison of data from the two sets of experiments;
c. to relate the flow behaviour of bimodal suspensions to real, complex nuclear slurries, since they represent a simple analogue thereof.

EXPERIMENTAL STUDIES

All experiments are being performed in the Sorby Environmental Fluid Dynamics Laboratory in the School of Earth and Environment. An existing slurry flow loop (Harbottle, 2008) will be used for the low viscosity and low particle concentration experiments with ultrasonic and optical measurements, while a second, new flow loop (Figure 1 and Figure 2) will be used for the high-viscosity and high particle concentration experiments with ultrasonic measurements methods.

Figure 1 Photograph of part of the new flow loop. Shown: tank, mixer, controls and UDVP probe on test section. Not shown: flow meter and pump.

Figure 2 Photograph of the probe holder that was designed and built for this purpose. There are slots for ultrasonic probes to be held at any angle between 0 and 90 degrees.

Initial flow results using the ultrasonic Doppler velocity profiler (UDVP) are presented in Figure 3. Data were obtained at *Re* = 48,400 and compare very well to the literature.

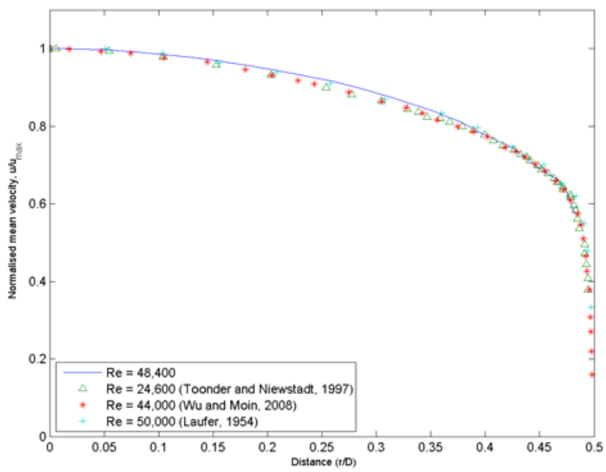

Figure 3 Mean flow velocity in tap water using the UDVP system. Data from Laufer (1954), den Toonder and Niewstadt (1997) and Wu and Moin (2008).

Initial particle sizing results with four species using the Philips XL30 SEM, Malvern Mastersizer (“high shear”), Formulaction Turbiscan (“low shear”) are shown in Figure 4. They suggest that aggregation significantly influences the effective size of the particulate phase and depends strongly on shear rate.

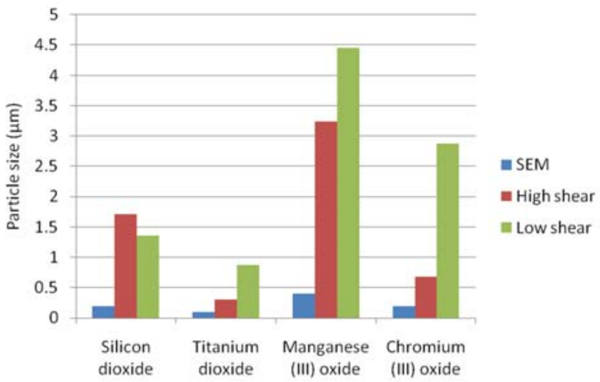

Figure 4 Particle sizing results for SiO_2, TiO_2, Mn_2O_3 and Cr_2O_3

FUTURE WORK

1. Additional particle characterisation studies with a range of particle species covering a range of densities ρ ~ 1-15 g cm^{-3} will be performed to investigate the effects of pH and particle concentration on effective particle size under static settling and flow conditions.
2. Optimisation of the new flow loop continues. We are developing new techniques to simultaneously measure the flow profile and effective particle size in flow conditions using attenuation spectroscopy.
3. Numerical studies to complement the experimental studies will be performed if time permits.

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