Particle Dynamics in T-junction High-Concentration Flow

J. B. R. Loureiro[1,2] and A. P. Silva Freire[1,2]

1: Interdisciplinary Center for Fluid Dynamics (NIDF/UFRJ), Federal University of Rio de Janeiro, R. Moniz Aragão No. 360, Bloco 2, 21941-972, Rio de Janeiro, Brazil.
2: Mechanical Engineering Program (PEM/COPPE/UFRJ), Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
*Corresponding author: miguel.panao@dem.uc.pt

Keywords: Biofuels, Sprays, Infodynamics, Phase-Doppler Interferometry.

ABSTRACT

The work describes sand-particle high-Reynolds number flow in a T-junction. Experiments are carried out for one different Reynolds number (R_e = 9.5x10^4), one typical particle diameter distribution (Mesh 150) and four sand concentrations (0.05, 0.1, 0.6 and 1.1 % w/w). The purpose of the work is to characterize the effects of indirect particle-to-particle interaction as particle load increases. PTV and PIV measurements are used to discriminate the velocities of the particles and the carrier fluid. The results shown that rebounding effects have a significant influence on particle dynamics.

1. Introduction

A subject of utmost importance to many technological problems is turbulent interactions between discrete particles and a fluid. In particular, particle erosion is a problem that plagues many important practical applications in the mechanical, chemical, nuclear, and petroleum industries.

Unfortunately, the very large number of variables that affect this interaction poses a considerable difficulty in devising experiments where effects can be isolated and adequately modelled. This is particularly true for heavily loaded systems (Nguyen et al. 2015).

Erosion modeling depends on such factors as the impact angle, velocity, size and shape of the solid particles. To determine these parameters experiments normally resort to controlled conditions with low particle fluxes (Parsi et al. 2014). Starved particle flows can have their dynamic properties more easily determined experimentally, since particle identification is more easily defined and measurements of the continuous and discrete phases can be decoupled. As long as particle-particle interaction is not significant, models can be developed on the assumption that erosion potential is directly proportional to the quantity of particles impacting onto a surface, independent of time. Also for the sake of simplicity, many experiments are carried out in air-particle flows.

Here, the effects of concentration on the velocity distribution of sand particles in water flow in a "T" geometry are discussed (Fig. 1). Experiments to characterize the dynamics of solid particles carried in a liquid are reportedly difficult to carry out in complex geometries. In solid-liquid systems, the trajectories of the particles and of the carrier fluid can be distinctly different. The present confined geometry is expected to induce complex particle rebounding effects, resulting in incoming particles being decelerated and thus having their speeds reduced.

The attenuation of erosion effects due to indirect particle-particle interaction is an aspect of erosion that has not been conveniently addressed in the literature. When a large number of particles are present in a confined flow, their common interactions become relevant as they are enhanced by enclosing walls. The tracking of individual particles in sand high-concentration flows is especially difficult in view of the increasing opaqueness of the field.

Here, the experiments are conducted at one Reynolds number (R_e = 9.5x10^4), one typical particle diameter distributions (Mesh 150) and four sand concentrations (0.05, 0.1, 0.6 and 1.1 % w/w). PIV and PTV measurements are used to characterize the properties of the continuous and the discrete phases.

The work shows that for concentrations over 0.1% the role of indirect particle-particle interactions becomes relevant. Also, it is shown that the side walls of the T-junction are particularly sensitive to particle erosion due to rebounding effects. The bottom impinging wall benefits from particles that bounce back and, on interacting with newly arriving particles, reduce the erosion rate. The implication is that the two side walls exhibit the most serious erosion damage, whereas the area that faces the main impinging flow shows nearly no erosion. This phenomenon had previously been noted by other authors (Zhang et al. 2017). Erosion ratio is the loss of mass surface caused by the mass of particles impacting on the surface.

2. Experimental conditions

The general flow geometry is shown in Fig. 1. Sand particles with an average 100 μm diameter and with concentrations varying between 0.05 to 1.1% (w/w) are dispersed in flows with R_e = 9.5x10^4. The surface material is aluminum. The Stokes particle number is of the order of unity. Particle Reynolds number (based on the relative velocities) varies in the flow domain but is normally very small, of the order of ten.

The black dots in Fig. 1 (left) denote optically identified sand particles. For the continuous phase velocity measurement, PIV was used. Particle velocities were measured through PTV. Both procedures were based on the software Dynamic Studio from Dantec^{TM} Dynamics.

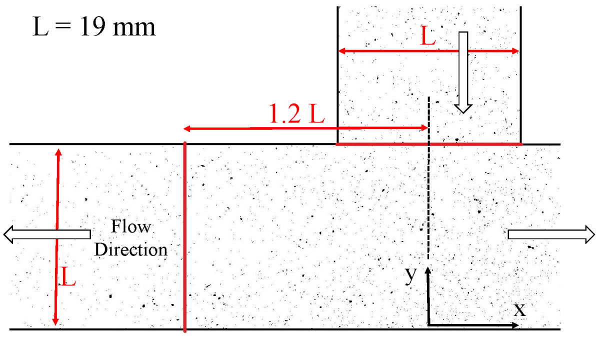

Figure 1. Flow geometry.

3. Results and Discussion

PIV measurements of the mean velocity and turbulent kinetic energy profiles are shown in Fig. 2 for R_e = 9.5x10^4.

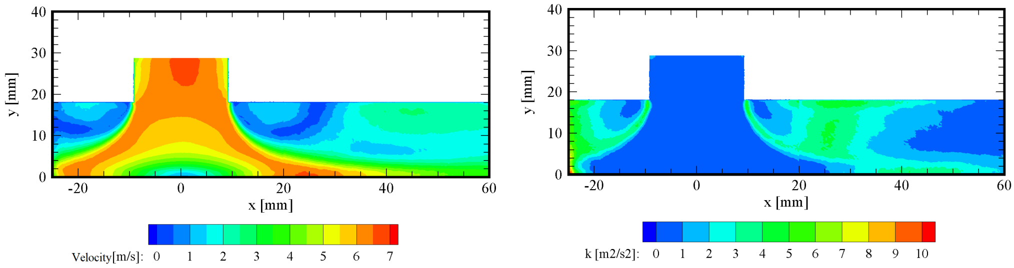

Figure 2. Mean velocity and turbulent kinetic energy profiles for R_e = 9.5x10^4.

The local particle mean velocity profiles at the *vertical* square-pipe exit (y/L = 1) are shown in Fig. . Results for *horizontal* square-pipe exit (x/L = 1.2) are shown in Fig. . Despite the large data scatter in Fig. , the evidence is that the particle mean velocity profiles change little with an increase in the concentration of particles. In fact, and as expected, the high concentration flows (0.6 and 1.1% (w/w)) tend to be slowed down close to the wall. The scatter in the horizontal pipe data is also very high. However, the particle mean velocity profiles show a distinct trend whereby flows with high concentration tend to be slowed down in the recirculation region and in the bottom near wall region.

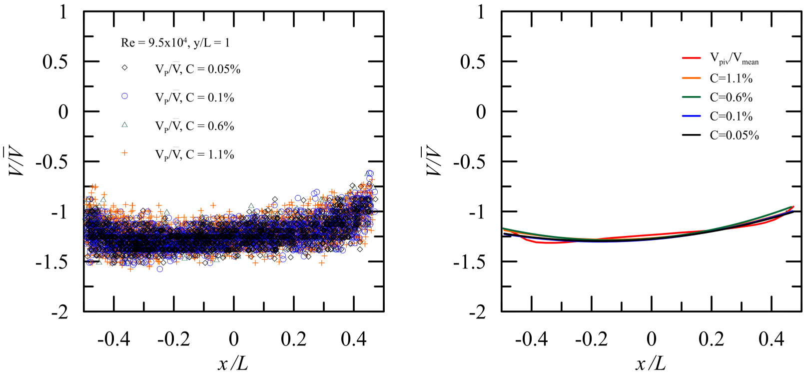

Figure 3. Particle velocity profiles at position y/L = 1 (vertical velocity). Left: All data. Right: averaged values.

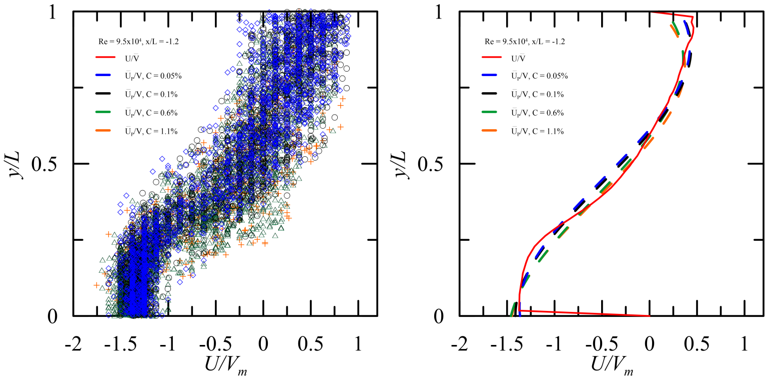

Figure 4. Particle velocity profiles at position x/L = -1.2 (horizontal velocity). Left: All data. Right: averaged values.

Figures. 5 and 6 shown the spatial distribution of particle velocities. The figures indicate that for the lower concentrations (0.05 and 0.1% w/w) the sand particles tend to follow the fluid trajectory. With an increase in sand concentration, indirect particle-to-particle interactions start to become important and occur as a result of rebounding effects and wake formation. In Figures. 5, the horizontal velocity component is strongly decelerated near the wall in the interval $x/L \in [-1, -2]$. The data shown in Fig. 6 is also relevant. Upward bouncing particles are observed to apparently damp the vertical velocity of incoming particles.

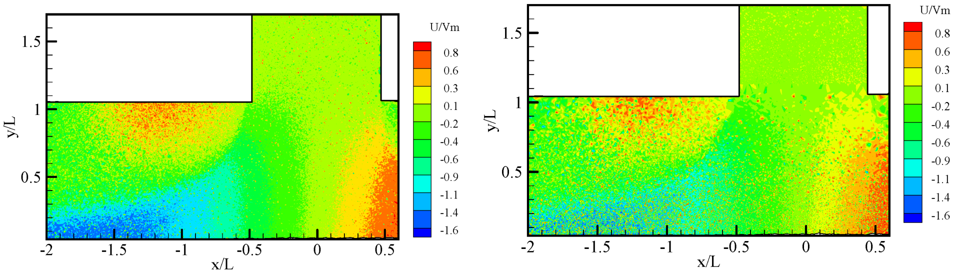

Figure 5. Effect of particle concentration on particle horizontal velocity (x-component). Left: 0.05 % w/w; right: 1.1 % w/w.

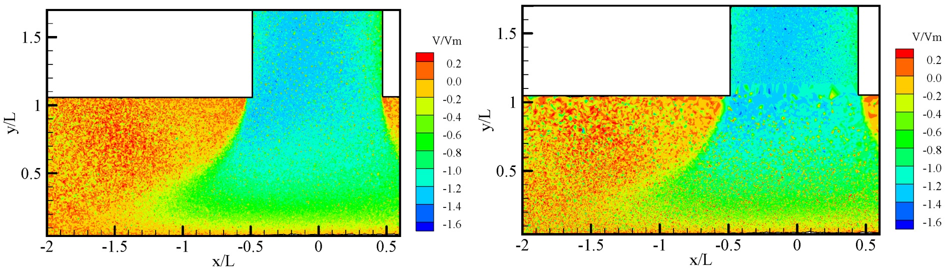

Figure 6. Effect of particle concentration on particle vertical velocity (y-component). Left: 0.05 % w/w; right: 1.1 % w/w.

The measured erosion rate (ER) for the side wall of the T-junction was 17,406 mg.h^{-1} for the sand loading condition of 1.1 % w/w. For the bottom wall, ER = 15,812 mg.h^{-1}. This difference was provoked by bouncing effects of particles.

Conclusion

The above work has described the effects of particle load on particle mean velocity profiles. The shielding effect is quantitatively characterized through PIV data and ER measurements.

References

Nguyen, V.B., Nguyen, Q.B., Lim, C.Y.H., Zhang, Y.W., Khoo B.C. Wear, Vol. 322-323, pp. 17–31, 2015.

Parsi, M., Najmi K., Najafifard, F., Hassani, S., McLaury, B. S., Shirazi, Journal of Natural Gas Science and Engineering, Vol. 21, pp. 850-873, 2014.

Zhang, J. X., Bai, Y. Q., Kang J. & Wu X. J. of Loss Prevention in the Process Ind., Vol. 46, pp. 94–107, 2017.