JOINT INVESTIGATION OF SETTLING AND PREFERENTIAL CONCENTRATION OF INERTIAL PARTICLES IN TURBULENCE

Sumbekova Sholpan[1], Alberto Aliseda[1], Alain Cartellier[1], Romain Volk[2] & Bourgoin Mickael [1]
[1] *Laboratoire des Ecoulements Geophysiques et Industriels, CNRS/UJF/G-INP UMR 5519, BP53, 38041,Grenoble, France*
[2] *Laboratoire de Physique, ENS de Lyon, UMR CNRS 5672, Lyon, France*

Abstract
Particle laden flows are of a great interest in many industrial and natural systems. When the carrier flow is turbulent, a striking feature named preferential concentration takes place: particles denser than the carrier fluid tend to inhomogeneously distribute in space, forming clusters and depleted regions. The present study aims at giving new insight into the possible connection between preferential concentration and particles settling in homogeneous isotropic turbulence. Preferential concentration is quantified using Voronoï diagrams, while 3D Lagrangian Particle Tracking is used to access particles dynamics and in particular statistics of settling velocity. Independent and joint statistics of local concentration and settling velocity will be discussed. Besides, the dependence of particles settling rates on clustering and turbulence levels is further investigated with the use of Laser Phase Doppler Interferometry.

A striking feature of turbulent flows laden with inertial particles is the so-called preferential concentration (or clustering) that leads to very strong inhomogeneities in the concentration field at any scale. This has now been widely observed in many experimental and numerical realizations including homogeneous and isotropic turbulence [1]. Althouhg the fact that the concentration field is more intermittent for particles whose Stokes number (defined as the ratio of the particle relaxation time to the Kolmogorov viscous time of the carrie turbulence) is close to unity, is a robust result in experiments and simulations, a theoretical description of preferential concentration remains a challenge, and the full set of parameters that rules this phenomena remains unclear. Similarly the possible connections between particles concentration field and particles concentration remain to be elucidated.

The clustering phenomenon has been analysed with the use of Voronoii tesselations obtained from snapshots of the particles in a given area in a flow field [1]. In this work, we have coupled the analysis of clustering to that of particles dynamics, with the goal to condition statistics of settling velocity to that of particles concentration. Two independent but complementary studies have been carried, using high speed imaging to couple Particle Tracking and Voronoï tesselation analysis on one side and Phase Doppler Inferometry (PDI) to capture statistics of particles arrival times and settling velocity statistics. These two methods give access to unprecedented statistics of settling velocity conditioned to particles local concentration field.

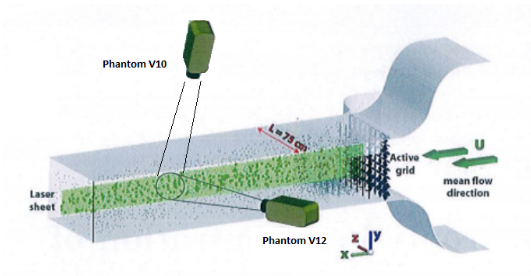

Figure 1. Sketch of the experimental setup.

Experiments are conducted in a large wind tunnel with a square cross-section of 0.75 m x 0.75 m (see Figure 1). Turbulence is generated with an active grid, capable to produce moderate turbulence with still relatively good homogeneity and isotropy levels. The mean velocity of the wind was varied from 3.4 m/s up to 7.6 m/s, corresponding to a range of Reynolds number R_λ from 230 up to 400. Inertial particles are water droplets generated by 18 injectors (a 6x6 mesh with identical spacing than the grid) located in a transverse plane 15 m downstream the grid. The average diameter of the particles is constant for all velocities: D_{32} = 60 μm (although size distribution has a significant polysdispersity of the order of 50%). A laser sheet (with milimmetric width) lightened the particles. Images were recorded with two high speed cameras (Phantom V10 and Phantom V12 from Vision Research Inc), with a field of view of the order of the integral scale of the carrier flow.

Particle Tracking Velocimetry

Particle Tracking Velocimetry enables the Lagrangian Measurement of the evolution of particles motion with time. In the present case, the use of 2 cameras allows to access all 3 components of particles velocity, but more importantly, the

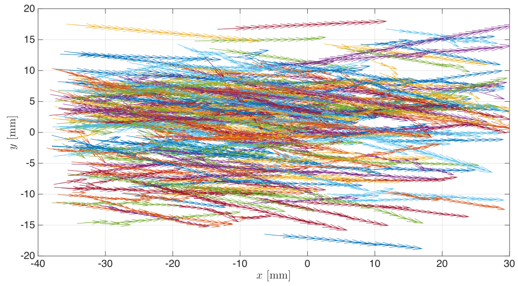

Figure 2. 2D Velocity vector field obtained from the results of PTV

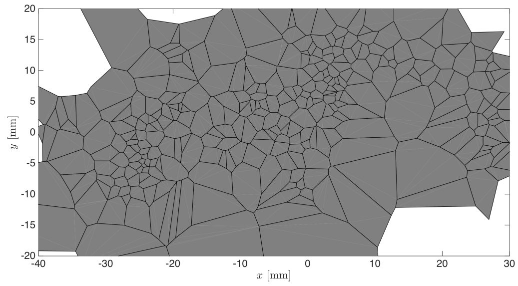

Figure 3. 2D Velocity vector field obtained from the results of PTV

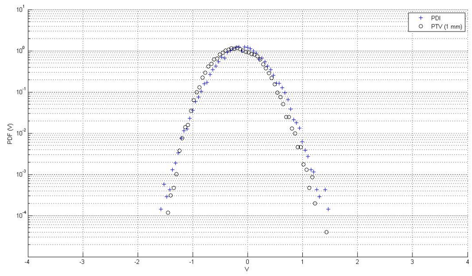

Figure 4. Comparison of the measurement of settling velocity by PTV and PDI

redundancy in the vertical direction (seen by both cameras) improves significantly the precision of the measurement of the settling velocity. Besides, from the position of the water droplets we perform Voronoï Analysis. Figures 2 and 3 represents examples of particle tracks and Voronoï tesselations in the experiment. On going analysis aim at coupling these two classes of information to access statistics of settling velocity conditioned on local concentration.

Phase Doppler Inferometry

The Phase Doppler Inferometry enables the simultaneous measurement of the velocity and the diameter of individual particles in the flow, hence allowing also a statistical conditioning on particles diameter. Besides, we can also infer particles concentration information using the particles arrival times coupled to a Taylor hypothesis, as a characteristic random variable of particles separation in the streamwise direction. Preliminary tests of the accuracy of the determination of settling velocity, taking many successive samples of 10000 events to study the statistical convergence of the analysis, show that 10 such series already give a good convergence on the determination of the average settling velocity. The results obtained show a very good convergence of the measurements of settling velocity. In particular, the measurements of settling velocity from PTV and PDI are in very good agreement (See Figure 4).

Discussion

Ongoing analysis focus now on the statistical conditioning of local concentration field (given by VoronoŢ areas from images or interparticle arrival times from PDI) and settling velocity. Measurements by Aliseda *et al.* [2] showed that settling was noticeably influenced by local concentration, but their study was limited to relatively low Reynolds numbers. Experimental data remains indeed very scarce regarding the evidence of such a collective effect in moderate and high Reynolds number regimes as we consider here. We will present a systematic characterisation of settling velocity conditionned to local and global particles concentraiton for different values of carrier flow Reynolds number (and hence also of particles Stokes number).

References

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