A new modelling framework for particle interactions in a high turbulent confined vortex

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Highly turbulent swirling flows are often used in spray drying due to their ability to enhance the overall heat and mass exchange rates. The high centrifugal inertia however promotes the concentration of particles close to the wall. It has been recently shown that the equilibrium established between the deposition and erosion of material plays a fundamental role in the flow dynamics of both the solid and fluid phases. It determines product residence time and it is the source of particle growth. In addition, the friction exerted onto the carrier phase disrupts the development of the vortex. The extent and symmetry of the deposits has been found directly related to swirl intensity decay rates and the appearance of a breakdown pattern (1).

In such conditions, the description of the dispersion, drying and interaction of airborne particles alone cannot be hold as a realistic representation of the system. Any integrated model shall be required to describe the deposition and erosion mechanisms that bring particles from an air to a wall borne state, as well as the evolution of the solid phase once it is bounded at the wall. It shall be required to incorporate the following inter-particle interaction mechanisms:

Deposition - Erosion mechanics: Yields exchange rates between the air and wall borne states.

Sintering within the deposit matrix: Yields a size change determined by the evolution of the solid bridge thickness during the residence time of wall-borne particles.

Coalescence of air borne particles: Nearby nozzle/s and wall regions it yields a size change determined by the size, relative velocity and drying state of the colliding partners

The implementation of any of the above however requires first detailed information of the air-borne system, particle concentration and velocity distributions and wall impact properties.

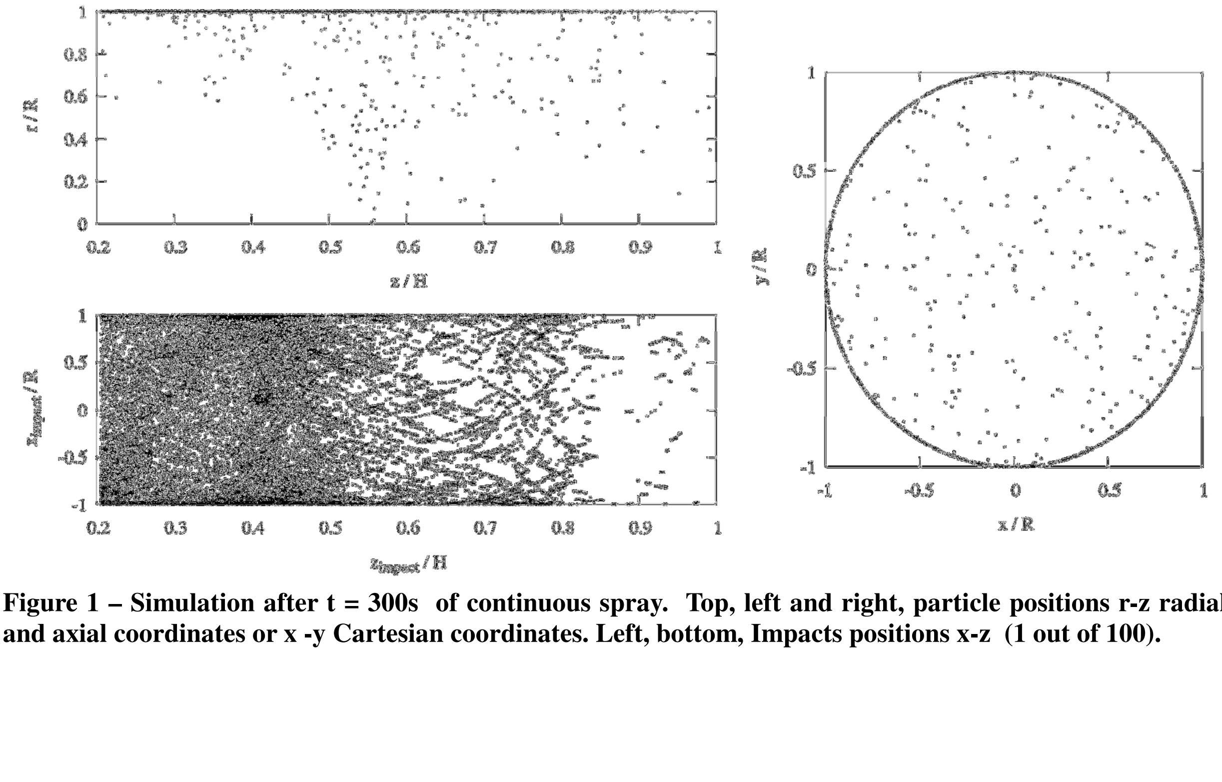

Figure 1 – Simulation after t = 300s of continuous spray. Top, left and right, particle positions r-z radial and axial coordinates or x -y Cartesian coordinates. Left, bottom, Impacts positions x-z (1 out of 100).

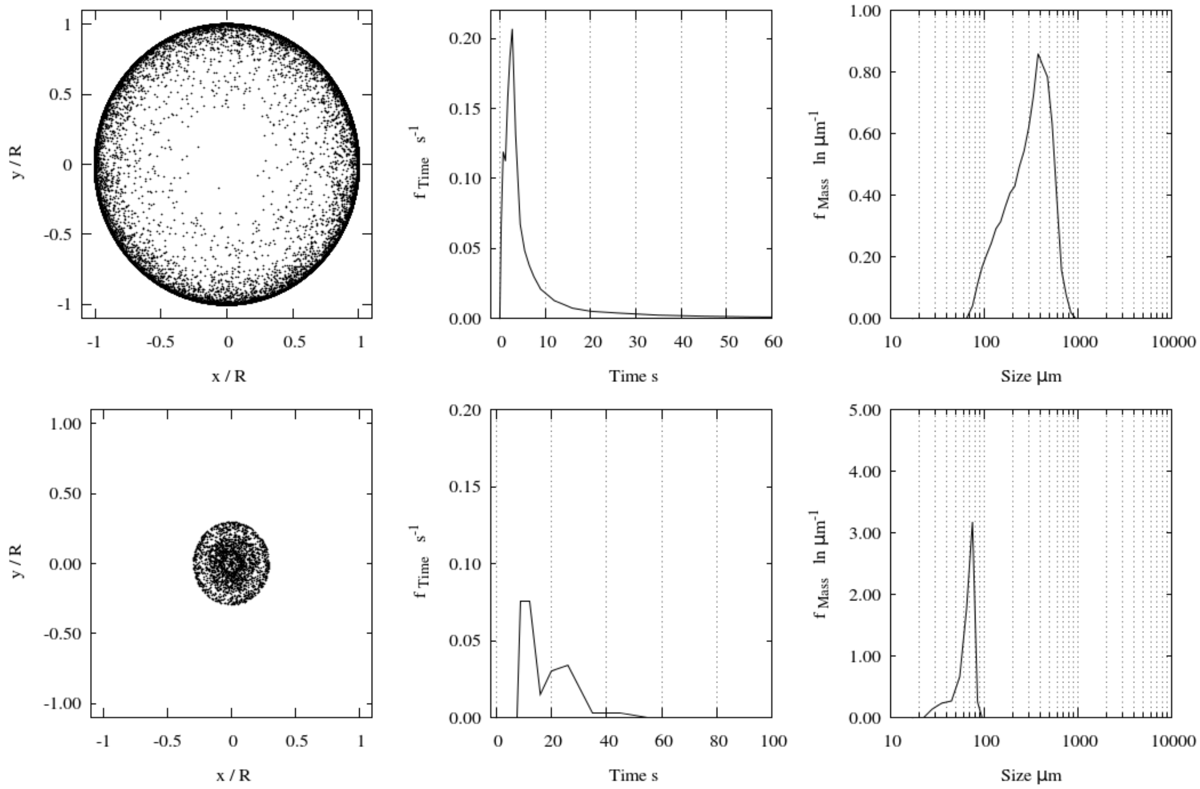

Figure 2 – Simulation after t = 300s of continuous spray. Top to bottom: Particles exiting via the top exit conduct z=H or via the bottom z= 0.2xH. Left to right, exit position, residence time and size distributions

The initial framework is provided by the development of an in-house Lagrangian particle dispersion model. It describes the evolution of air borne particles and incorporates models for the turbulent dispersion, wall contacts and single droplet drying, along with experimental data describing the nozzle/s injection. It is written to be executed upon a grid providing the carrier phase properties, such as a coarse experimental data grid -where the appropriate reconstruction scheme is applied- or directly coupled with the grid obtained from a numerical simulation from a fluid dynamics package. Prior to incorporating of any particle growth models, a sensitivity analysis has been conducted to investigate the effect of all flow dynamics parameters on the particle dispersion and the distribution of wall impacts. Figure 1 & 2 provide typical examples of the spatial distribution of air-borne particles and wall impacts, as well as the estimated residence time and particle size distributions for the product and the re-entrained fines.

Two considerations arise from this work: the relevance of contact parameters, in particular wall roughness, and the definition of the structure of the turbulent boundary layer. Both have an important effect in the recirculation patterns observed close to the wall, promoting subsequent ejections of particles in and out the boundary layer. Turbulence is particularly relevant for a range of size fractions, close to that seen to exit through both the bottom and top ends (60-110 µm in figure 2). At first, such sizes are entrained upwards. While a fraction is dragged inwards towards the top exit, other experience strong enough centrifugal forces to be brought to the low velocity regions close the wall where it starts falling and its concentration rises significantly. Two effects follow. Firstly, coalescence is promoted as such stagnated particles sweep across the spray projection comprised by high velocity droplets, and secondly a driving force for the erosion of material from the deposits follows the large number of wall impacts generated.

1. Francia, V. Martin, L. Bayly, A.E. Simmons, M.J.H. *The role of wall friction in the development, decay and breakage of an air turbulent confined vortex*. Proceedings of the 8th International Conference on Multiphase Flow. Jeju, South Korea, 2013.