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Vortex formation in a strongly coupled dusty plasma flow past an obstacle

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Self-generated vortex flows are observed in many dusty plasma experiments and has been dealt with considerable attention recently. In a typical situation self-excited vortices are found to be due to nonzero curl of the plasma forces on the dust particles e. g in rf discharges, microgravity condition and associated with subsonic dusty plasma flow with low Reynolds numbers.[1,2] Experiments have been attempted to generate vortices by externally induced flow in dusty plasma e.g. laser radiation, neutral gas flow and probe induced flow.[3] In particular, vortex patterns are well known in hydrodynamics and other physical systems (e.g. aerodynamics) when fluids or gases flow past an obstacle or vice versa. In numerical simulation, vortex formation leading to Karman vortex strait has been observed when Reynolds number of the dusty plasma flow is varied.[4]

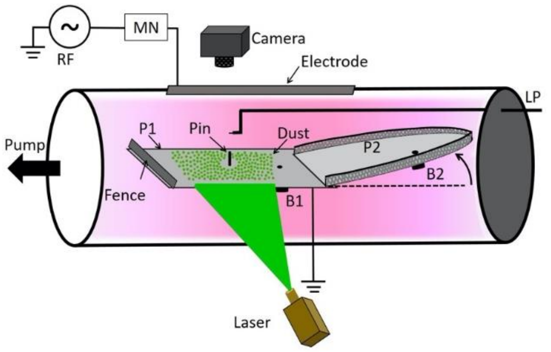

Fig. 1. The schematic of the experimental device.

The experiment is done in a simple borosilicate glass cylinder of 100 cm in length and 15 cm in radius.[5] Plasma is produced by RF power at argon 1-3x10^{-2} mbar. Silica particles ~5 micron in diameter are levitated above the lower plate forming the dusty plasma. Dust flowing at different velocity 3- 10 cm/sec) towards a void is managed to observed the structure formation behind the void.

A typical example of the vortex pair formation is shown in Fig. 2 (left panel) at different time interval. The shear viscosity and hence the kinematic viscosity of the dusty plasma medium are measured and found to be comparable with reported values.[6] When flow velocity is smaller than dust acoustic speed a laminar dust flow does not lead to vortex formation. Vortex formation occurs when flow speed is comparable or slightly larger than the dust acoustic speed and a unsteady laminar flow is maintained. The Reynolds number for vortex formation is in the range $60 \leq \mathrm{Re} \leq 90$ which is larger in comparison to the hydrodynamic fluid.

The flow is analyzed using a MATLAB based open access PIV code. Typical data (velocity vectors and vorticity profile) are also shown in Fig. 2 (right panel) superimposing velocity vectors for a selected duration. The vorticity $(\vec{\nabla} \times \vec{v})$ value of the vortices varies from 12 s^{-1} to 25 s^{-1} during the course of its formation, which is nearly twice the measured corresponding angular frequency.

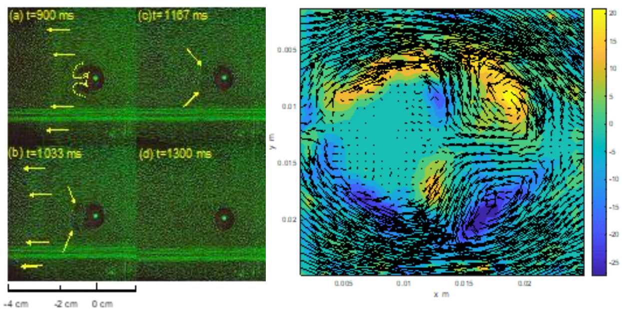

Fig. 2. (L) Snapshots of video image data at different time interval during vortex growth. (R) PIV analysis of video image data showing the velocity vectors and vorticity values.

We have carried out a molecular dynamics simulation using an open source classical Large scale Atomic/Molecular Massively Parallel Simulator which replicates the PIV analysis of observed phenomena. In the present experiment vortex shedding is not observed possibly due to limitation of continuous dusty plasma fluid flow for longer time as well as due to larger neutral drag which introduces heavy dissipation. However, we demonstrate the clear evolution of pair of counter rotating symmetric vortex when dusty plasma flows past an obstacle/void associated with electrostatic potential.

References:

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