NUMERICAL SIMULATION OF ACOUSTIC WAKE AGGLOMERATION OF MICROPARTICLES IN AEROSOL

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1. General

Acoustic agglomeration is a process in which intense sound waves produce relative motions among fine mostly the micron-sized solid aerosol particles, where they touching each other form agglomerates. Understanding of particles behaviours in acoustically induced aerosols flows is essential from both engineering and theoretical points of view. Several application areas such as air pollution control and the improving of performance of air cleaning devices could be mentioned [1].

From the mechanical point of view, an aerosol is treated as the dispersed fluid which is assumed to be diluted so that particle–particle interactions and two-way coupling effects can be ignored. The acoustic wake presents hydrodynamic mechanism which produces agglomerative motion of particles through the surrounding medium because of hydrodynamic forces and the asymmetry of the flow field around the particle. A theory describing the acoustic wake effect based on Oseen flow fields was first proposed by Pshenai-Severin [2]. Further studies [3] and [4] are based on deriving an analytical solution for two nearby particles differently orientated with respect to the direction of the acoustic field. Interaction of the sound induced motion with gravity yields more complex refilling agglomeration mechanisms.

Recent developments of the discrete element method (DEM) [4]-[5] using the Lagrangian approach and Newton's laws of classical mechanics opened new vistas on the acoustic wake. The purpose of this work is to improve understanding of acoustic wake in presence of multi-particle interactions and gravity.

2. DEM approach

The conventional DEM approach was modified for simulation of agglomeration. The translational motion of an arbitrary particle p with mass m_p in viscous incompressible fluid is characterized by time t dependent position and velocity vectors of the particle mass centre $\boldsymbol{x}_p(t)$ and $\boldsymbol{v}_p(t) = \dot{\boldsymbol{x}}_p(t)$, respectively. The equation of motion is written in a vector form as follows:

(1) $$m_p \dot{\boldsymbol{v}}_p(t) = \boldsymbol{F}_{Sp}(t) + \boldsymbol{F}_{Dp}(t)$$

Here, $\boldsymbol{F}_{Sp}$ is a sedimental force comprising gravity and buoyancy, while $\boldsymbol{F}_{Dp}$ a drag force comprising the Stokes force and the so called "Oseen's correction". The problem is solved numerically by time integration of equations of motion (1). The detailed description of DEM acoustic agglomeration model can be found in [5]-[6].

3. Problem description

The motion of micron-sized glass spherical particles characterized by the density $\rho_p = 2400$ kg/m^3 is simulated numerically. The air medium is considered as viscous incompressible fluid. At temperature 20ºC it is characterized by the density $\rho_m = 1.293$ kg/m^3 and the dynamic viscosity $\mu_m = 17.9 \cdot 10^{-6}$ m^2/s. External acoustic excitation presents the monochromatic sinusoidal sound wave propagating horizontally in plane Oxy. The wave is characterized by the amplitude velocity $V_{s0} = 0.44$ m/s (SPL 136 dB) and the frequency $f = 3$ kHz.

4. Numerical results

Acoustic wake phenomenon is illustrated by considering binary interaction between two identical particles with diameters equal to $d = 8$ µm. The particles are separated by the initial distance 40 µm, and they are aligned along the sound direction. Selected simulation results are presented in Fig. 1. Theoretical solution in terms of particles trajectories [3]-[4] obtained for isolated particles exhibits tuning fork character and illustrates perfectly symmetric vertical motion (Fig. 1a). This motion is characterised by constant vertical velocity $v_y = 0.0045$ m/s, which is actually the terminal velocity of the particle (Fig. 1c, graph – No box).

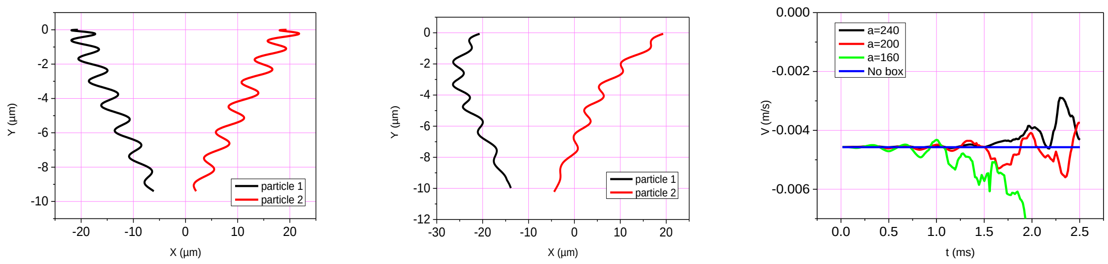

Figure 1. Trajectories of particles – isolated particles (a) and in presence of surrounding particles (b) and time histories of the vertical velocities (c) of the first particle

Application of the DEM opened new opportunities to discover multi-particle contribution of neighbour particles. To avoid direct contacts, two particles are isolated by imaginary rectangular bounding box having different sizes *a* equal to 240 µm, 160 µm and 80 µm, respectively, while the contribution of other particles is evaluated by the long-distance effects. These effects are illustrated in Fig. 1b and by new graphs in Fig. 1c. Results show that surrounding particles disturb regular agglomerative motion.

5. Concluding remarks

DEM is a proper numerical analysis technique to describe binary and multi-particle interactions of particles under acoustic excitation. It was shown that presence of neighbour particles disturb regular agglomeration patterns obtained by isolated wake mechanism.

6. References

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