Experimental study on particle settling dynamics in stratified ambient conditions

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ABSTRACT

Sedimentation is a significant mechanism of particle transport in the ocean and lakes. The transport of particulate organic matter, such as detritus and marine snow, is a crucial element of the ocean carbon cycle with further implications to the ocean productivity and climate. Furthermore, our understanding of sedimentation dynamics of microplastic pollutants in marine systems is necessary to improve our knowledge on the fate of these hazardous substances in natural environment.

It has been already demonstrated that density stratification inhibits descent of particles, especially at sharp density interfaces (pycnoclines) (Prairie et al. 2015). However, our understanding of these processes is still insufficient. The well-established Stokes formula has been usually applied in sedimentation studies to assess the settling velocity and to model the descent of marine particles, assuming that particles are perfect spheres settling in a homogeneous liquid in a low Reynolds number regime. Recent experimental and numerical studies (Camassa et al. 2009) have shown that this approach may lead to misestimating of settling dynamics when applied in stratified ambient conditions, i.e., vertical density gradients, which are characteristic of oceans and lakes. It has been acknowledged that stratification is a source of additional drag which causes unexpected deceleration of settling spheres (Srdic-Mitrovic et al. 1999). Moreover, numerical study (Doostmohammadi and Ardekani 2014) has shown that elongated particles settling in a low Reynolds number regime reorient while crossing density interface as the effect of buoyancy-induced torques.

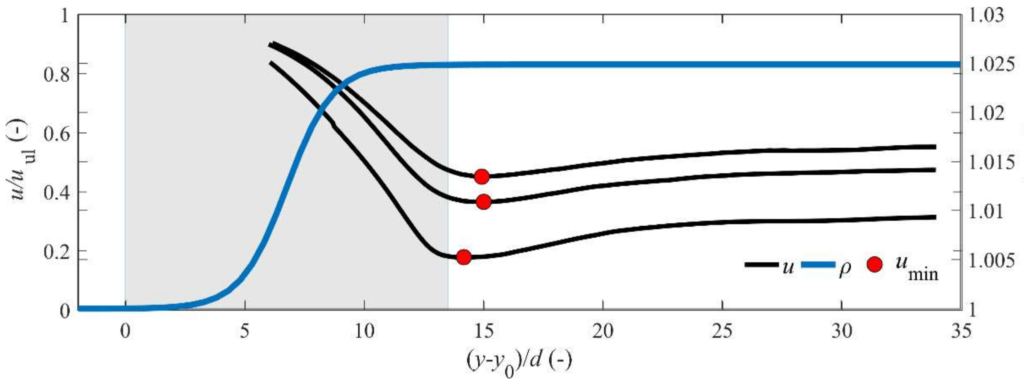

Fig. 1. Normalized settling velocity of a sphere and density profile in a two-layer water column with density transition (grey area) as a function of the distance from the upper boundary of density transition. u – instantaneous settling velocity, u_{ul} – terminal settling velocity in upper layer, u_{min} – minimum settling velocity, ρ_f – density of ambient liquid, ρ_{ul} – density of upper layer liquid, y – distance, y_0 – location of upper boundary of density transition, d – particle diameter.

In this presentation, I show laboratory studies on particle settling in a two-layer water column with the density transition between the two homogeneous layers. The aim of these studies is to analyse the effect of density transition represented by buoyancy frequency and density jump between homogeneous layers on the settling velocity of spheres and settling behaviour (velocity and orientation) of disks.

Experiments were performed in the Laboratory of Hydrodynamic Micromodels, Institute of Geophysics, Polish Academy of Sciences. Specially designed tanks were filled with aqueous salt solution to form two-layered system. The settling process was visualized using shadowgraph method, recorded images were processed to obtain orientation of particles and settling velocity using particle tracking method.

Experiments on sphere settling have demonstrated patterns similar to those presented in previous studies. Figure 1 presents sample results showing that a sphere achieves the minimum settling velocity just after leaving the density transition. Experiments on settling behaviour of non-spherical particles have revealed some new findings on the effects of stratification (Mrokowska 2018): A disk settling through density transition undergoes complex settling velocity and reorientation patterns dependent on density transition thickness, stratification strength and density difference between upper and lower layers. These results may have significant future implications on our understanding of microscale and large-scale biogeochemical processes, e.g. by improving the estimation of particle retention times at pycnoclines.

References

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