This highlight refers to the PhD Thesis by Sina Tajfirooz (2021)

Numerical methods for dynamics of particles in magnetized liquids

With applications in magnetic density separation of end-of life plastic

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In the wake of the ever-increasing worldwide production of plastic, now more than ever before, the inefficiency of our current plastic recycling strategies has become evident. Plastic pollution has become a major environmental, economic and societal concern. Different types of plastic (PET, PVC, PS, etc.) are inherently incompatible. Mixing different plastic types through the recycling process leads to the so-called "down-cycling" of high-quality plastic products to low-grade single-use products that cannot be recycled anymore. A main challenge in the plastic recycling industry is the efficient separation of different types of plastic.

Magnetic density separation (MDS) is a state-of-the-art mechanical separation technique that separates plastic particles of different types based on minute differences in their mass density (as low as 1 kilogram per cubic meter). MDS uses engineered magnets and a magnetically responsive liquid to create a non-linear pressure field inside the liquids. A schematic of an MDS system for separating plastic particles is shown in Figure 1. Once a mixture of plastic waste is injected, in the form of particles, into a continuous flow of a magnetic liquid, the combined effect of gravitational and magnetic buoyancy forces pushes the particles to heights unique to their mass density. Different mass density groups can then be continuously extracted from the system using separator plates mounted downstream of the flow at different heights.

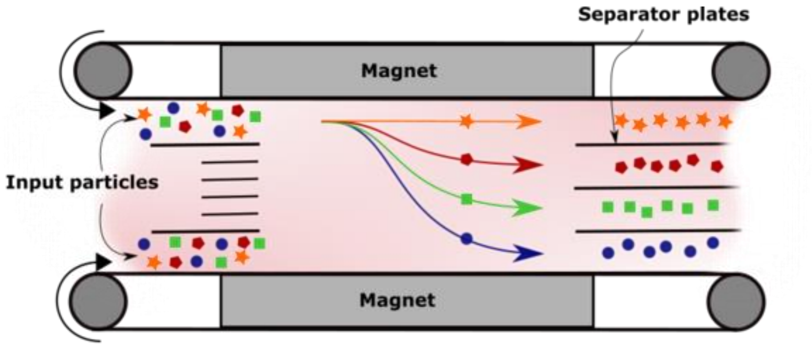
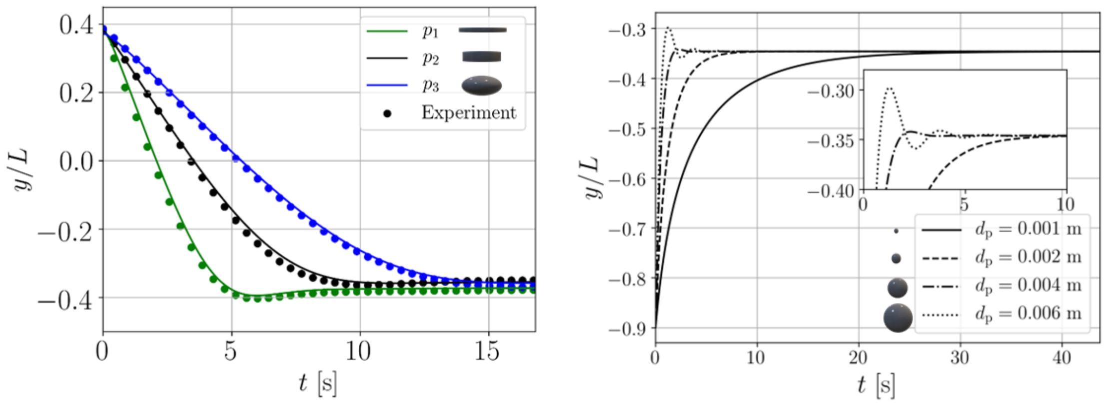


Figure 1: A sketch of the magnetic density separation system. Each marker (color) indicates a different mass density.

Optimizing MDS systems requires a fundamental understanding of the motion of millimeter-sized, arbitrarily-shaped particles in flows of magnetic liquids. This work develops an efficient computational framework to predict and understand particle-laden flows in MDS systems.

We use a point-particle Euler-Lagrange approach (PP-DNS) to capture the motions of magnetic fluid and immersed particles. Our computationally efficient point-particle method models the two-way fluid-particle momentum transfer by introducing local forces to the fluid momentum equation at the position of the particles. The collisions between the particles are also captured by accurate collision detection and response models. Moreover, to capture steady hydrodynamic interactions of highly non-spherical particles immersed in particle-laden flows, we combined a statistical-learning method with resolved CFD simulations to build accurate and versatile force and torque correlations for such particles.

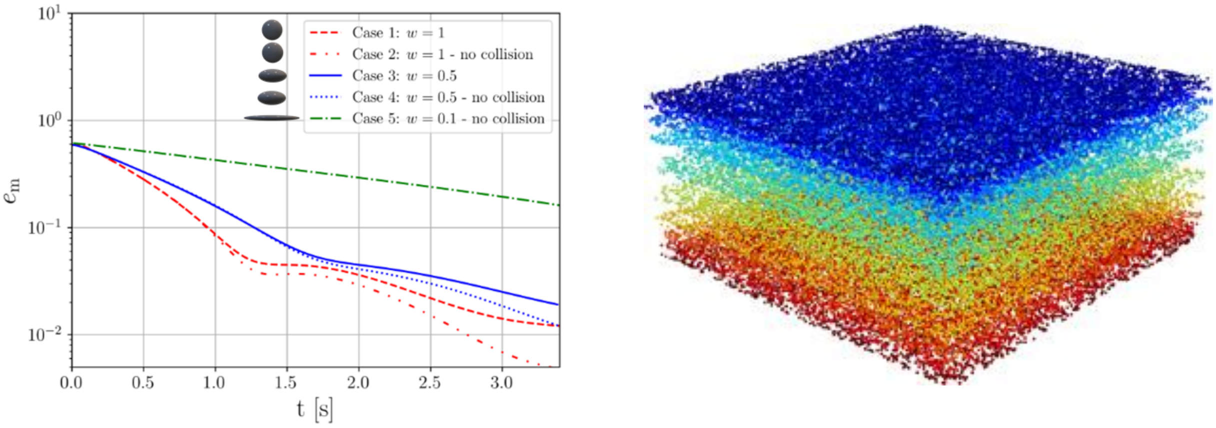
We first validated different elements of our model by comparing the numerical results with detailed experiments performed in a lab-scale MDS setup consisting of one or two particles. Next, we employed the model to investigate large MDS systems. We quantified the effects of particle size, shape, and collisions on the MDS performance. Figure 2 shows the effects of particle shape and size on the motion of single spherical particles in a magnetized liquid. Larger particles separate more quickly. In addition, spherical particles are separated faster than thin disk-shaped particles.



(a) (b)

Figure 2: Effects of (a) particle shape and (b) size on the traveling time of a single particle inside a magnetized liquid. Particles p_1, p_2, and p_3 particles have aspect ratio 0.1, 0.2 and 0.5 respectively.

The effects of particle shape and collisions on the separation efficiency of large MDS systems are shown in Figure 3a. Separation performance is quantified by separation error e_m, defined as root-mean-square of particle distances from their theoretical equilibrium points. Figure 3b shows a snapshot of spherical particles (case 1) after 3 seconds. In large MDS systems, the hampering effect of collisions is larger for more spherical particles. However, overall, the spherical particles exhibit a better separation performance. Hence, it would be beneficial if the particles could be pre-processed to be roughly spherical. The findings of this work can be effectively used to optimize future MDS systems.



(a) (b)

Figure 3: (a) Effects of particle aspect ratio, w and collisions on the separation error e_m. (b) A snapshot of spherical particles consisting of ten mass density groups after 3 seconds. Each colour represents a mass density.

Reference

Tajfirooz, S. 2021. Numerical methods for dynamics of particles in magnetized liquids, PhD Thesis, Eindhoven University of Technology.