New in-orbit self-assembly principles and manufacturing techniques

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Overview

Many materials (e.g. different types of inorganic and organic alloys) in the liquid state consist of fine particles or droplets dispersed in an external (fluid) matrix. Once the effects of gravity are no longer felt, the different densities of the involved phases no longer represent a constraint forcing the dispersed particles or droplets to separate from the fluid through sedimentation or flotation; exploring self-assembly principles becomes therefore possible. Self-induced particle ordering is indeed emerging as one of the most relevant or promising approaches to develop in-space heterogeneous systems or materials consisting of parts that can recognize and bind to each other or form specific templates or patterns.

Case Experience

The author has almost 30 years experience in the exploration of microgravity phenomena and processes. Relevant examples pertaining to this branch of microgravity research at the University of Strathclyde are the JEREMI project, i.e. the Japanese European Research Experiments on Marangoni Instabilities (funded in UK by EPSRC) and the PARTICLE VIBRATION project (also known as T-PAOLA i.e. "Thermovibrationally-driven Particle self-Assembly and Ordering mechanisms in Low grAvity" (funded by STFC/UKSA) experiment (*www.t-paola.co.uk*).

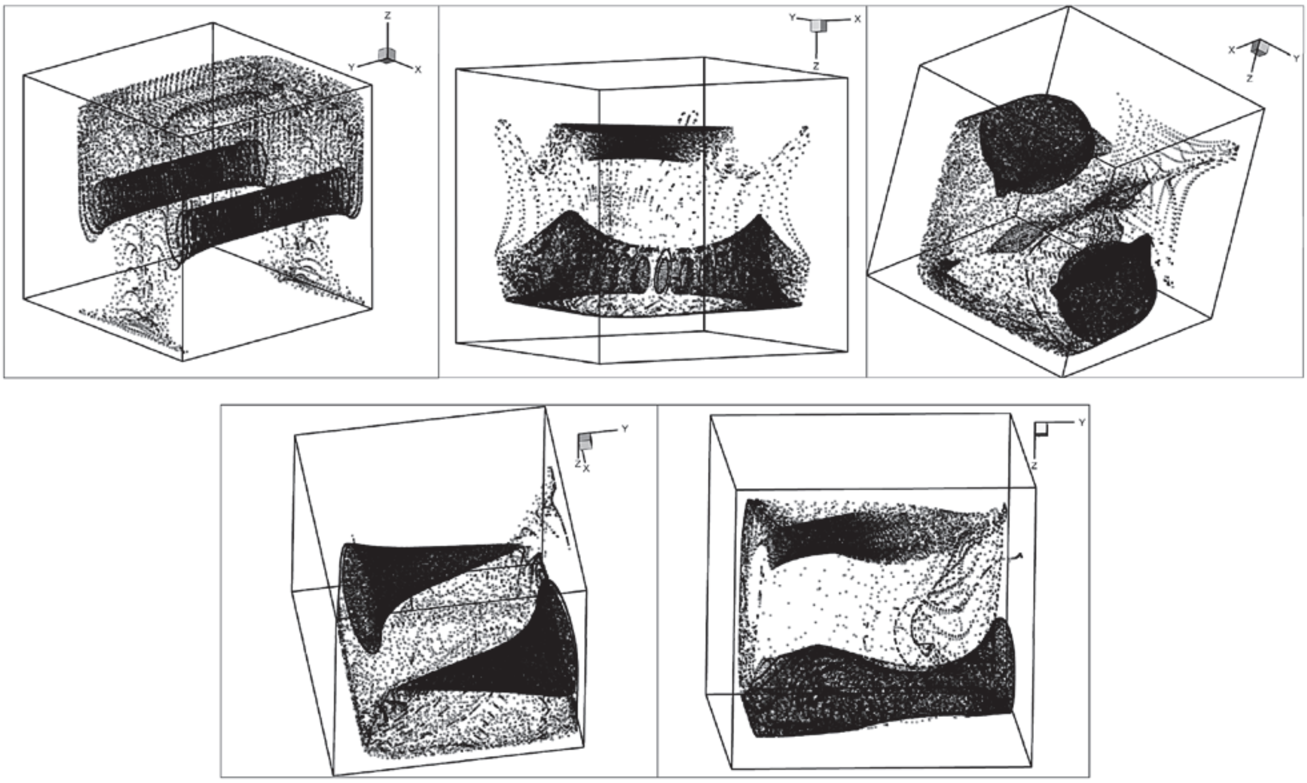

Figure: Examples of structures spontaneously formed by particles in a non-isothermal vibrated dilute liquid-particles system in microgravity (computer simulations).

These projects have been conceived to identify or define new concepts to manipulate matter on different scales and develop accordingly new contactless solid-particle manipulation strategies, i.e. novel methods to force particles dispersed in a fluid matrix to target certain regions of the physical space without touching them. In particular, while the former experiment relies on thermocapillary (Marangoni) effects, for the latter, the main mechanism driving macroscopic fluid flow and particle self-organization is driven by thermovibrational effects, namely, convection induced in a non-isothermal cubic enclosure by the application of vibrations with given frequency and amplitude. The PARTICLE VIBRATION experimental campaign (PI M. Lappa) was conducted on board the International Space Station from the beginning of February to the end of April 2023, resulting in a successful validation of the proposed vibration-based particle control approach. All the required experiments were executed using the Microgravity Science Glovebox (MSG NASA facility) in combination with the Selectable Optical Diagnostic Instrument (SODI, ESA facility).

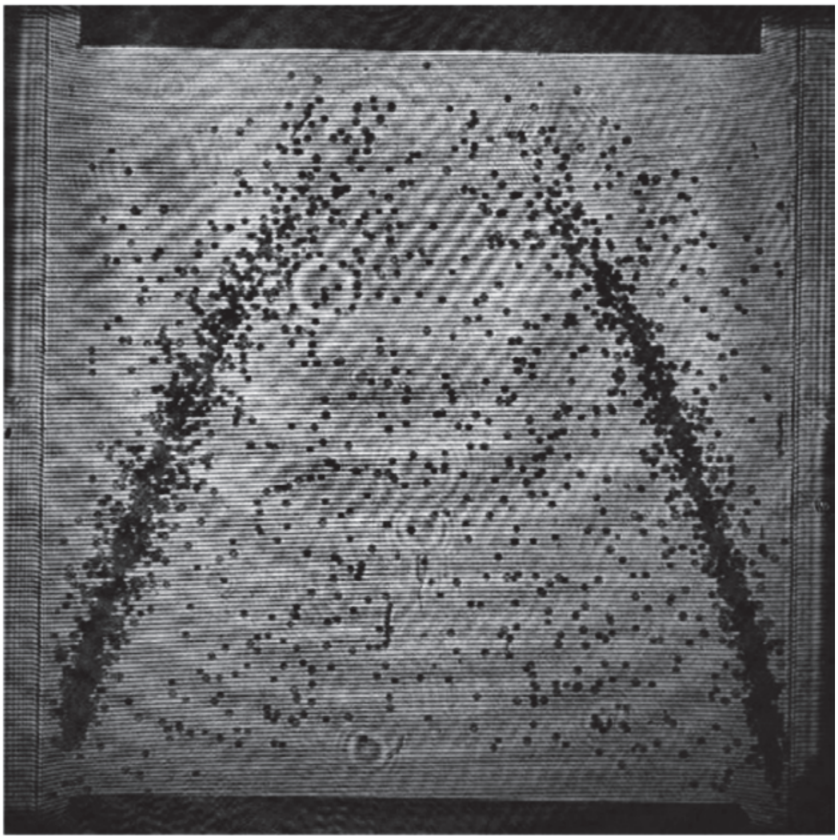

Figure: Side view of particle structures formed in microgravity conditions (T-PAOLA experiment).

Opportunity for Research and Innovation

The new level of understanding provided by these experiments conducted in space is opening the way to innovative applications in chemistry, physics, and biomaterials and inorganic materials science. The availability of a new method to control multiphase systems, which consist of a minority phase dispersed into a majority phase, will lead to improved and/or completely 'new' materials in space with properties that cannot be obtained on Earth. These include, but are not limited to, immiscible metal alloys, polymers composites, plastic materials and even many macromolecular substances used for the production of drugs and medicines (which are typically obtained in the form of seeds which nucleate in an external fluid phase). The new proposed technique based on the use of thermocapillary or thermovibrational effects can be regarded as a much more universally applicable method because, unlike other control strategies based on the application of magnetic or electric fields, it does not require the considered media to be electrically conductive or sensitive to magnetism.

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