SEGREGATION OF SUSPENDED PARTICLES IN A ROTATING FLUID-FILLED HORIZONTAL CYLINDER – EXPERIMENT AND THEORY

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Summary An extensive experimental investigation into the segregation phenomenon of suspended particles in a rotating fluid-filled horizontal cylinder is presented as well as a theoretical approach to the underlying physics, based on the assumptions of small Ekman and Rossby numbers. The theoretical predictions agree well with experimental findings. The influence of non-linearity and viscosity on the phenomenon will be discussed as well.

The phenomenon of spontaneous banding of suspended particles in an almost inviscid fluid-filled rotating horizontal cylinder is part of a family of seemingly similar segregation phenomena occurring when two or more phases are embodied in a rotating horizontal tube. Other related phenomena are the axial segregation in a mixture of granular materials placed in a rotating horizontal cylinder [1] and the segregation of neutrally buoyant particles in a partially filled rotating horizontal cylinder [2].

The phenomenon was first observed several years ago as part of a study on the influence of anisotropy on the character of dendritic crystals [3]. In order to prevent interaction with any substrate a supersaturated solution of NH_4Cl was put in a closed horizontal cylinder and rotated about its axis - thus attaining microgravity conditions by which the growth could be examined. As the crystals nucleated a most curious and counterintuitive scene was observed – the crystals tended to accumulate in specific periodic bands perpendicular to the axis of rotation (FIG.1).

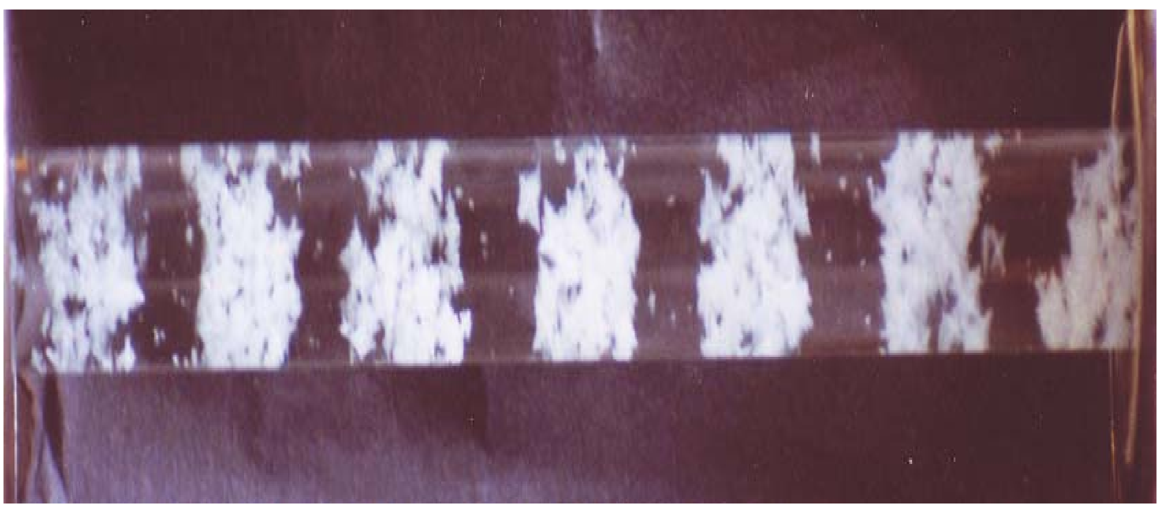

FIG.1 Banding phenomenon of NH_4Cl crystals in a supersaturated solution

In order to investigate the main features of the, as yet, mainly unexplored phenomenon we performed several experiments in which we checked the dependence of the periodic spacing between bands on tube length and the dependence of the phenomenon on the size and shape of the particles, as well as on the tube diameter. The experimental apparatus used was a basic mechanical system designed to rotate glass tubes about their horizontal axis.

The surprising results, presented in the generic graph of FIG. 2, indicate a robust phenomenon, independent of particle size or shape as well as of the bounding cylinder diameter. Moreover, a preference of a constant periodic length equal to 3.6R (R being the tube's radius) is observed throughout the experiments.

In addition, an extraordinary phenomenon of oscillation between two possible band configurations was observed. These oscillations, resembling the well-known oscillations between two coupled pendulums from classical mechanics and the Rabi oscillations between two coupled states in quantum mechanics, were investigated as well in order to understand the underlying physics.

An attempt was made to explain the phenomenon of segregation, based on the linear Navier-Stokes equation [4]. Here we assumed the suspended particles to be the source of a periodic disturbance (in the rotating frame of reference) to the otherwise rigidly rotating fluid. This assumption, together with the assumption that in the interior the effect of viscosity is negligible, led to the conclusion that traveling inertial waves, having a unique flow pattern, which could cause the observed axial segregation into bands, are excited.
Our approach is essentially different from a recently published approach [5], which accompanied the report of the occurrence of the same phenomenon, but with more viscous fluids, and which is based on the assumption that the inertial terms are negligible (creeping flow approach).

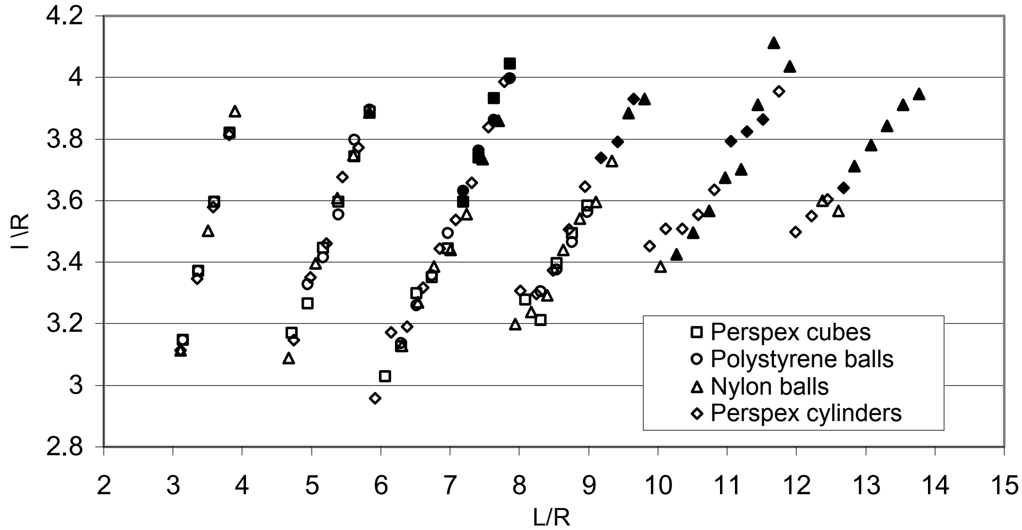

FIG. 2 A compendium of all data gathered in the investigation of the dependence of periodic length (l) on tube length (L) for particles suspended in water (full markers represent observed oscillations between two possible band patterns). The coordinates are scaled by tube radius in-order to manifest general features of the banding phenomenon.

We intend to present the results of the experimental investigation as well as the theoretical approach, the predictions of which well correlate the experimental findings.
We also will discuss the effects of non-linearity and viscosity, which were neglected in the theory, on the phenomenon.
A video clip, illustrating the dynamical evolution of the oscillations between two interleaving band patterns will be presented.

References

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