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Avalanches of Concentrated Granular Suspensions Down an Inclined Plane

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Abstract. To gain insight into the dynamics of geophysical flows, we carry out experiments with granular suspensions made up of spherical non-buoyant particles within a Newtonian fluid. The refraction index of the fluid matches the particles' refraction index so that the suspension is transparent. Part of the particles are tagged with fluorescent dye and activated with a laser sheet. Particles are tracked using a high speed camera. This makes it possible to measure the flow characteristics inside the bulk (e.g., density and velocity profiles) far from the sidewall. A typical experiment involves releasing a fixed volume of suspension (10 l) down a 3.5-m-long and 10-cm-wide flume.

Keywords: Suspension flow, Debris flow, Dam Break, PIV, PTV
PACS: 47.57.E-, 47.57.Gc, 47.57.ef, 47.61.Jd, 47.80.Cb, 47.80.Jk

INTRODUCTION

Many geophysical flows involve suspensions of solid particles within a fluid. For some flows, the volume solid fraction is very high, i.e., exceed 50%. A typical example is provided by debris flows, i.e. water-saturated poorly sorted sediment flowing down an slopes, driven by gravitational forces [1]. Since these flows cause substantial damage and death toll, there is a rising demand for more realistic computational models that are able to predict their main characteristics.

Most natural flows usually take the appearance of viscous fluids flowing down a slope. This observation has prompted the use of fluid-mechanics tools for describing their motion [2]. However, impediments to this approach are numerous. In any fluid-mechanics approach, the crux lies in the proper formulation of the governing and constitutive equations. Describing non-Newtonian materials in complex flow geometries remains a challenging task: for natural flows, initial conditions are generally not known, boundary conditions are ill-known and can vary with time (e.g. erodible basal surface), material can change with time and/or position. A wide range of particle sizes (often in the 10^{-6}-to 1-m range) makes the definition of mean particle size delicate. In addition, even with the construction of specifically devoted large rheometers, testing the rheometrical properties of samples collected in the field remains difficult for a number of reasons (truncated particle size range, segregation, etc.)

To gain insight into the dynamics of geophysical flows, we investigate time-dependent flows in the laboratory, which mimic the behavior of full-scale flows. We use model suspensions made up of solid spherical particles within a Newtonian fluid (in practice, a blend of several oils to make the suspension transparent). The density of the Newtonian phase can be adjusted such that the particles are buoyant or not. Using image processing techniques, we track tagged particles inside the flow; particles are tagged with fluorescent dye (Rhodamine). Emphasis is given to particle concentration and velocity profiles. Two flow geometries are studied: a viscometric flow in a Couette cell (coaxial-cylinder geometry) and a dambreak flow (time-dependent flow induced by the collapse of a fixed volume of fluid down a flume). Rheometrical experiments are presented in Wiederseiner's paper [3], while dam-break experiments are outlined here.

MATERIAL AND PROCEDURES

We used PMMA (Polymethyl methacrylate) beads provided by Arkema. These beads were quite spherical and exhibited appropriate optical properties. Their mean diameter was 200 μm. Newtonian solutions were made up of

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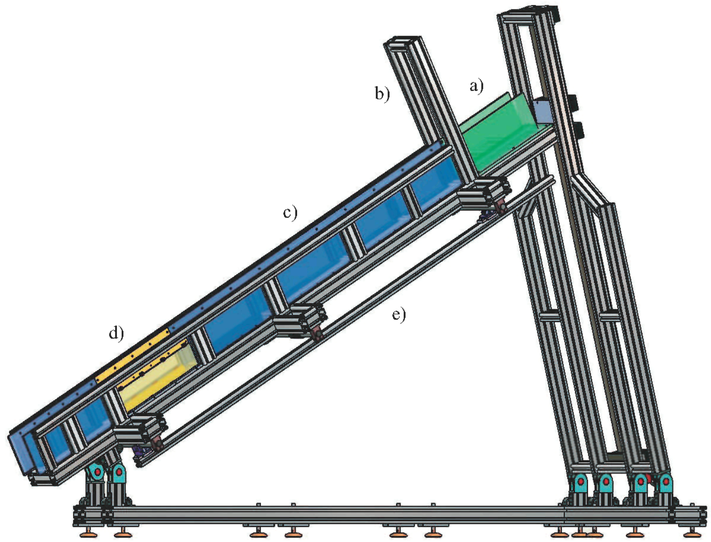

FIGURE 1. Sketch of the experimental facility: a) reservoir, b) dam opened by pneumatic jacks, c) aluminum plate to ensure rigidity, d) optical glass panes to observe the particles inside the flow, e) guide for optical lenses.

three different fluids: Dibromohexane, Triton X100, and UCON 75H450 silicon oil. When preparing and using the fluids, special attention was paid to working at constant temperature because refraction index and density changed a great deal with temperature. To hinder particle sedimentation, suspension temperature was controlled to within 0.1°. We tagged a few particles by immersing and heating them in a Rhodamine-ethanol solution.

A laser sheet was produced using one spherical and three cylindrical lenses. With this set-up we completely controlled the geometrical characteristics of the sheet: it was possible to build divergent sheets with a varying angle or parallel-side sheets. Width and focusing distance were adjustable [4]. We used a dual-cavity Nd:YAG laser, which was able to be operated at a frequency of 30Hz (180 mJ per pulse) coupled to a 4-megapixel PIV camera. We placed a filter in front of the camera, which cut off all wavelengths that are below 540 nm; in this way, Rhodamine which once excited emits light in the narrow range around 560 nm was clearly visible in the images.

EXPERIMENTAL FACILITY

The facility is made up of an aluminum frame supporting an inclined channel and a reservoir, as sketched in Figure 1. The channel is 3.5 m long and 10 cm wide. The sides of the flume are made up of 1-mm thick aluminum plates and profiled aluminum beams of section 40×80 mm^2 to ensure a good rigidity. The channel inclination ranged from 0° to 30° to within 0.1°.

In order to control the density and the refraction index of the fluid, we kept the temperature of the suspension constant during experiments. For this purpose, the channel was enclosed in an isolated room, whose temperature was fixed at 20 ± 0.2 °C using a fan coil unit. The completely closed reservoir of 10 l was positioned at the top of the channel. It has the same width as the channel, is 50 cm long and of 20 cm high. The fluid temperature inside the reservoir was controlled by a cryostat and a water circuit surrounding the walls. Small windows on each side, at the top and the bottom of the reservoir, allowed to checking the transparency of the suspension and possible sedimentation. The dam made up of a 5-mm aluminum plate is opened up by a pneumatic jack. An electromagnetic sensor located on the jack gave the reference time for the experiment and synchronized the other instruments. Two 500×150 mm^2 glasses were located 2 m downstream of the dam and made it possible to track activated fluorescent particles inside the avalanching mass. We used optical optical glass to avoid optical distortion.

The laser sheet was created underneath the channel and aligned perpendicular to the bottom with a mirror tilted at

45°. All the optical axis was mounted on linear stages and could be shifted from one side to another one. This made it possible to measure velocity profiles inside the flow at different positions across the stream. Different roughened bottom plated were used. In order to avoid reflections of the laser sheet at the interface between the flume bottom and fluid, we used Altuglass to build up the flume bottom. Altuglass has the same refraction index as the PMMA particles.

CONCLUSION

We built up an experimental setup to measure velocity profiles, migration, and segregation inside flowing suspensions. Using isoindex suspensions, we were able to take measurements far from the sidewalls for time-dependent flows. In the poster, we present our preliminary results obtained with this setup. Comparing our results and the rheometrical data produced by Wiederseiner [3] with the same model suspensions should help understand the complex dynamics of highly concentrated suspensions.

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