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The remarkable nondecelerated spreading of shear-thickening suspensions

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Introduction

Unsteady gravity-driven flows are common events at the earth's surface (e.g., debris flows, lava flows, landslides). Modelling them is therefore a major challenge for understanding landscapes and forecasting risks. For this purpose, the idealized dam-break configuration, in which a large fluid volume is released and spreads on a solid surface, has been intensively studied using Newtonian and non-Newtonian fluids, granular materials, particulate suspensions, among others. Despite this vast literature and in-depth knowledge, the case of discontinuously shear-thickening suspensions has not been addressed until now. Yet, the remarkable behaviour of discontinuous shear-thickening is quite general as it only requires a liquid containing a sufficient fraction of microscopic repulsive particles. When the imposed stress exceeds the short-range repulsive force, the grain contact interaction transits from frictionless to frictional, resulting in an abrupt change from a liquid-like to shear-thickened or jammed suspension. The consequences of the frictional transition have mainly been investigated in rheometers. However, a few studies on more complex hydrodynamic flow configurations have revealed that such suspensions adapt to flow in surprisingly different ways, and it is still unclear in a highly unsteady free-surface flows.

Method

This work tackles this question by experimentally studying the dam-break flow of discontinuous shear-thickening suspensions. The setup consists of a triangular volume of suspension prepared at the bottom corner of an inclined channel. The flow is then triggered by suddenly tilting back the channel to horizontal. Most experiments are carried out with aqueous suspensions of cornstarch grains - a widely documented shear-thickening system - for which the volume and the volume fraction of particles are varied systematically. Other types of shear-thickening suspensions, composed of various particles and fluids, are also used to confirm the universality of the results. Flow spreading is characterized by probing the temporal evolution of the flow thickness profile and the front position combined with surface flow-velocity measurements.

Results and Conclusions

By first comparing the spreading of a discontinuous shear-thickening suspension with that of a viscous Newtonian liquid, we reveal a major difference in the morphology and dynamic propagation of the flow. In constrast to the highly decelerated, rounded creeping flow of a Newtonian liquid, the spreading of a discontinuous shear-thickening suspension is characterized by a step-like profile - a flat upper surface with a vertical front – propagating with a nondecelerated front velocity. This nondecelerated spreading is particularly surprising because it means that the front velocity depends neither on the flow height, which drives the flow through the hydrostatics, nor on the flow spread, which sets the drag through the no-slip condition at the ground. Visualizations of the surface flow velocity show that this nondecelerated, step-like spreading is accompagnied by a surface overspeed at the front, suggesting that the flow is localized within a thin layer beneath the surface, while the suspension below would be close to be jammed. Based on these observations, we provide a minimal model to describe the nondecelerated regime, which proves relevant for a wide variety of gravity-driven flows. Finally, this study provides guidelines for a better interpretation and modelling of complex geophysical flows.