Lubricated gravity currents of power-law fluids

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Friction can substantially impact the pattern and stability of viscous flows, ranging from tiny drops to massive ice sheets and beyond. When the fluid is non-Newtonian with a viscosity that is dependent on the rate of strain, the response can be further amplified. We explore the impact of friction on a gravity-driven axisymmetric flow of a power-law fluid experimentally[1] and theoretically[2]. We present laboratory experiments of a gravity current of a strain-rate softening fluid (polymer solution) over a flat surface that was lubricated by another gravity current of a relatively inviscid and denser Newtonian fluid (sugar solution). The resulted patterns can be described in terms of the flux ratio of the Newtonian to the non-Newtonian fluids. We found that when that flux ratio was sufficiently small, such coupled flows remained axisymmetric (Figure), and propagated faster than non-lubricated gravity current, though with a similar power-law exponent. In contrast, nonaxisymmetric stream patterns arose when the flux ratio got larger than $\sim 1/10$. We explore the axisymmetric patterns theoretically in a model of coupled gravity currents, consisting of a power-law fluid lubricated by a Newtonian fluid. We find that the structure imposed by the non-Newtonian flow generally precludes self-similarity, unlike purely Newtonian fluids. Consequently, we identify outstripping solutions in which the front of the lubricating fluid outstrips that of the power-law fluid through two potential mechanisms. The first arises when the viscosity ratio of the two fluids grows beyond a critical value, and the second arises when the exponents of the power-law fluid and of the discharge rate satisfy a certain relation. To leading order and without fitting parameters the theoretical predictions of the non-Newtonian fluid front and thickness evolution are consistent with the experimental measurements. The same applies for the front of the lubrication layer. Discrepancies suggest the presence of hydrofracturing or wall slip near the fronts, and potentially, a progressive significance of extensional stresses as front outstripping is approached.

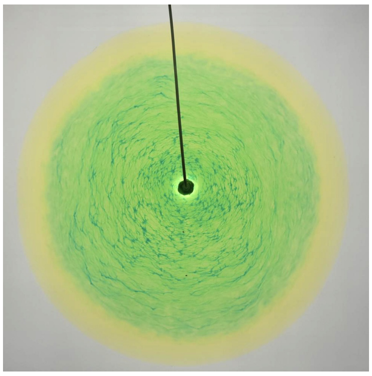

Figure 1: Plan-view snapshot from a laboratory experiment[1] of a lubricated gravity current that consists of a strain-rate softening fluid (yellow) lubricated by a sugar solution (blue, appears green)

[1]P. Kumar, et al., *J. Fluid Mech.* **916**, A33 (2021).
[2]A. Gyllenberg and R. Sayag, *J. Fluid Mech.* **949**, A40 (2022).