Rivulet flow of a power-law fluid

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The draining of a gravity-driven rivulet of fluid occurs in a wide range of practical and industrial contexts, such as geophysical flow of ice, lava and mud, and rain–wind-induced vibrations of cable-stayed bridges and coating processes. Inevitably most of the theoretical work has been focused on rivulet flow of a Newtonian fluid; however, despite the importance of non-Newtonian behaviour in many practical contexts, there has been comparatively little work on rivulet flow of non-Newtonian fluids.

We show how the solutions for the unidirectional steady gravity-driven flow of a thin rivulet of a power-law fluid with prescribed volume flux down a planar substrate can be used to describe both the flow of a slowly varying rivulet with prescribed contact angle but slowly varying width (as sketched in Fig. 1) and the flow of a slowly varying rivulet with prescribed constant width (i.e. pinned contact lines) but slowly varying contact angle (as sketched in Fig. 2 and 3) draining in the azimuthal direction from the top to the bottom of a large horizontal circular cylinder. In particular, we show that the global behaviour is qualitatively different in these two cases, and for narrow and wide rivulets with constant width.

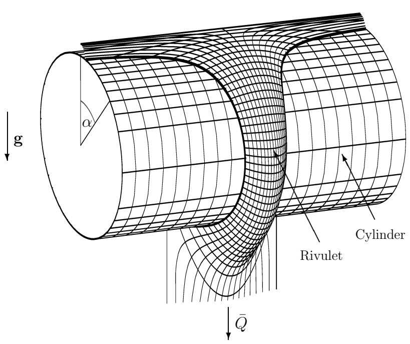

Figure 1: Sketch of a rivulet with constant contact angle around a cylinder

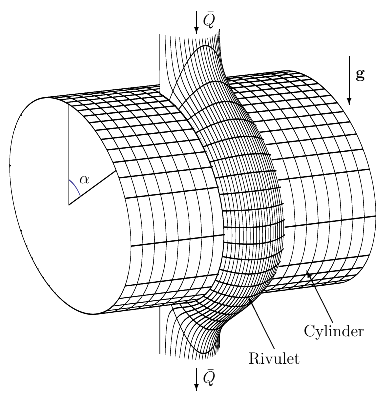

Figure 2: Sketch of a narrow rivulet with constant width around a cylinder

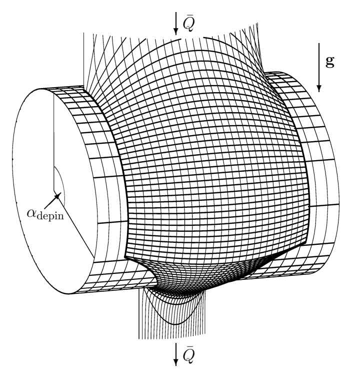

Figure 3: Sketch of a wide rivulet with constant width around a cylinder

We also show how the features of the solution are strongly influenced by the shear-dependence of the viscosity. For instance, the flow of a rivulet of strongly shear-thinning fluid "self-channels" down a narrow central channel between two "levées" of slowly moving fluid that form at its sides, and in the central channel the velocity profile has a "plug-like" form except in a boundary layer near the substrate. On the other hand, for a strongly shear-thickening fluid the velocity profile is linear except in a boundary layer near the free surface.

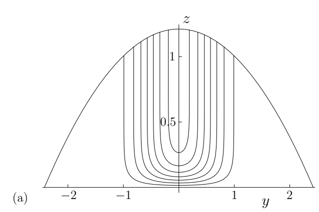

Figure 4: Contour plot of the velocity for a strongly shear-thinning fluid.

References

[1] F. H. H. Al Mukahal, B. R. Duffy, and S. K. Wilson, A rivulet of a power-law fluid with constant contact angle draining down a slowly varying substrate, submitted to Phys. Fluids (2015).