Towards an understanding of electrostatic assist: Experiments and models for electrohydrodynamic deformation of liquids in cavities

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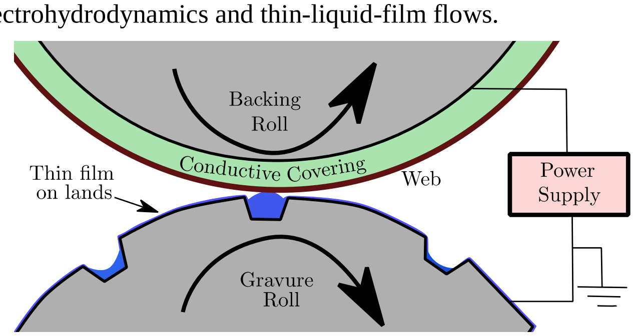
Gravure printing is a high-speed roll-to-roll printing process based on the transfer of ink from cavities on the gravure roll to a substrate on the backing roll. Electrostatic assist (ESA) is a procedure that uses strong electric fields to pull ink out of gravure cavities, thus enhancing ink transfer and reducing printing defects. Although ESA is widely employed, its underlying principles have not received a rigorous treatment. To gain insight into ESA, we study the simplified, related problem of deformation of a Newtonian liquid within a cavity via flow visualization experiments and models.

We present an experimental setup to visualize the meniscus deformation for liquid in a cavity. We construct cavities in two distinct geometries in a metal block: a 2d groove and an axisymmetric cylinder. Liquid is filled within the cavity and a second metal block or gold-plated glass slab serves as the top electrode. We probe the effects of (i) electric parameters (DC field strength, liquid conductivity), (ii) system geometry (cavity shape, liquid level, air gap above the cavity), and (iii) fluid properties (surface tension, viscosity) on the shape and timescale of evolution of the liquid meniscus. In all our experiments, the liquid interface is observed to attain a steady deformed state at low electric field strengths. However, a steady state is not attained above a critical field strength and the liquid meniscus evolves until it contacts the top electrode. Further, the qualitative shape of the evolving meniscus is found to strongly depend on liquid conductivity and different modes of meniscus growth are seen for non-conducting and conducting liquids, which could lead to single or multiple points of contact of the liquid with the top electrode.

Through an electrohydrodynamic model, we probe the effect of several of the experimental parameters on meniscus deformation. The model succeeds in capturing the distinct deformation modes observed in the experiments, and provides physical insight to explain them. In addition to being relevant to ESA, the model problems we consider are also of fundamental interest in and represent novel contributions to the areas of electrohydrodynamics and thin-liquid-film flows.

(a) 

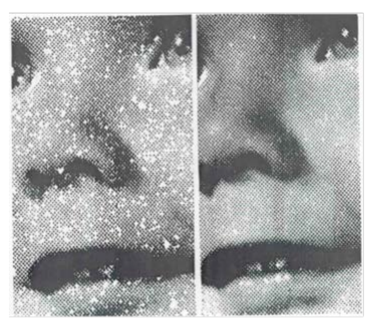
(b) 

Figure 1: (a) Schematic of Electrostatic Assist, (b) Gravure printed image with (right) and without (left) electrostatic assist.