LIQUID TRANSFER IN GRAVURE PRINTING PROCESSES: A NEW NUMERICAL APPROACH TO STUDY THE EFFECT OF CAVITY SHAPE

Diego M. Campana (*, **) and Marcio S. Carvalho (**)

(*) Instituto de Desarrollo Tecnológico para la Industria Química (INTEC)
Universidad Nacional del Litoral, CONICET, Guemes 3450 (3000), Santa Fe, Argentina.
email: dcampana@santafe-conicet.gov.ar

(**) Department of Mechanical Engineering, Pontificia Universidade Católica do Rio de Janeiro,
Rio de Janeiro, RJ 22453-900, Brazil
email: msc@puc-rio.br

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Industrial printing processes, such as gravure and flexography have gained great attention in last years because of its potential applicability to the fabrication of polymeric solar cells and other flexible electronic devices, which are basically printed on a flexible substrate. Dodds et al. (2009) have used a 2D-axisymmetric numerical model to study the liquid transfer from a cavity full of liquid to a flat moving plate. The model supposes a liquid bridge formed between both the cavity and the plate, which eventually brakes when the plate is moving away from the cavity at constant velocity (only under extension). They did a careful parametric study to investigate the effect of wettability, capillary number, cavity shape and other parameters on the fraction of liquid ϕ transferred from the cavity to the plate. The results show that the amount of liquid transfer is primary controlled by the cell shape and surface properties, being extremely important the pinning experienced by the contact line on the cavity wall. Although they suggested a cavity with steeper wall and sharp corners could promote more severe pinning effect, no results were included to support this suggestion.

This work is an extension of the aforementioned paper, mainly focused on the following aspects:

(i) Build a more flexible formulation and numerical technique which permit us to solve complex cases in 2D and 3D simulations.

(ii) With this new numerical tool extend the results of Dodds et al. (2009).

To complete the first objective, we use basically the same numerical technique of Dodds et al. (Galerkin finite elements method) but with some modification. One of them is the introduction of unstructured meshes of triangles and a new associated algorithm to move and adapt the mesh to the deforming domain; this makes easier the discretization of complex geometries (see Fig. 1). The other important modification is the method to impose the boundary conditions: we implement a Lagrange's multiplier approach to introduce restrictions in the variables on boundaries. With this approach both linear and non-linear equations (restrictions) can be easily and cleanly imposed giving flexibility and versatility to the code. One example of this is the shape of the cavity wall, which is modeled here with the equation $z = -1/2(1-tanh(r-r_c)/r_s)$, being r_c and r_s two parameters that control the size and shape of the cavity. A discussion of the advantages of this method over others regarding free surface flows can be found in Sprittles and Shirkmurzaev (2012). We used the commercial software COMSOL Multiphysics to implement the model because the referred Lagrange's multiplier method is the default working approach and also because its flexibility to make specific model formulations.

To test the new approach in 2D simulations we built cavities with steeper wall and sharper corners than those used in Dodds et al. (2009). This was done by varying the r_s parameter in the previous equation, while $r_c = 0.8$ (Fig. 2).

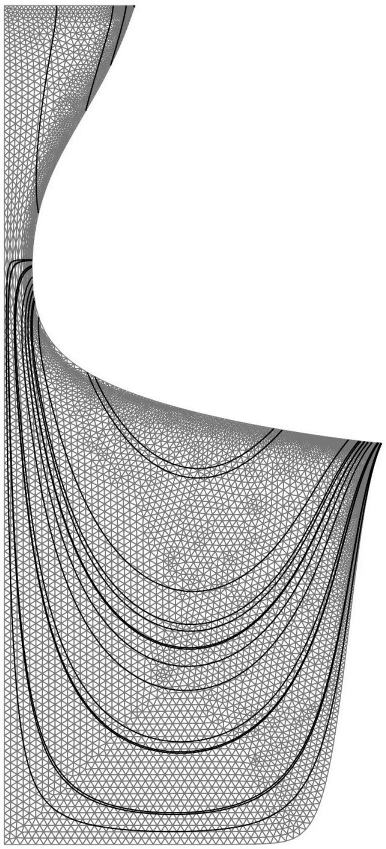

Figure 1: Example of the unstructured mesh discretizing the deforming domain.

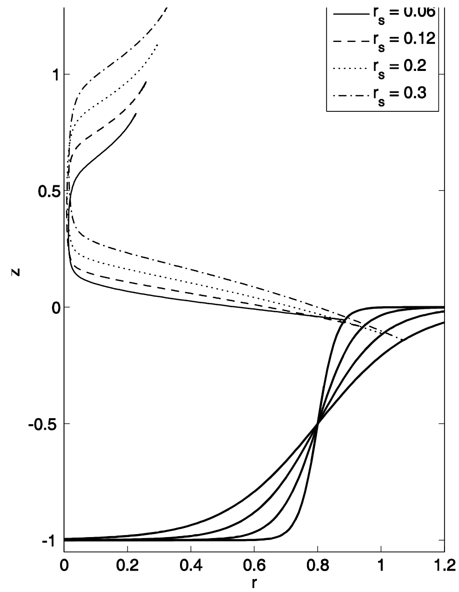

Figure 2: Interfacial position at breakup for different cavity shapes. The smaller the r_s parameter the higher the wall slope

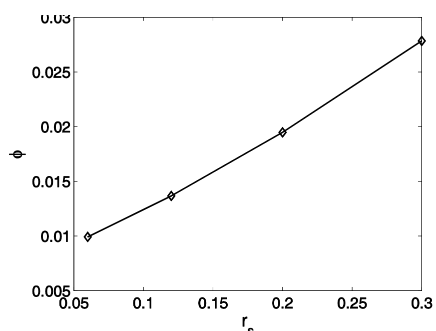

Figure 3: Liquid fraction ϕ vs cavity shape parameter r_s.

The new results confirm Dodds's suggestions that the liquid transfer is mainly controlled by contact line pinning, because as the wall is made steeper the contact line travels a smaller distance inside the cavity and the breakup of the bridge is anticipated.

Thus, the pinning promoted by the wall shape limits the liquid fraction transferred to the moving plate (see Fig. 3).

Regarding 3D simulations, in a recent work Dodds et al. (2012) explored the extension of liquid bridges with moving contact lines, as a model to analyze the reproducibility of patterns during printing. With the new technique we could also extend these results by introducing a more realistic kinematic (extension plus rotation) to the moving plate.

At present we are trying to develop a better model of the liquid transfer; one challenge is improving the kinematic description of the relative movement between surfaces and the other is the simulation of more realistic cavity shapes in 3D.

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