Stretching of Liquid Bridges containing Gas Inclusions

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ABSTRACT

The transient extensional flow of a liquid bridge between two plates plays an important role in applications such as inkjet and gravure printing. Gravure is commonly employed to print materials at high volumes, such as magazines/catalogues, stamps and labels. Apart from its use in graphics arts industry [1], gravure printing is also used for several cutting-edge applications, including the printing of electric circuits, antennas, solar cells and photocatalytic coatings. In gravure printing (Figure 1) a roll is engraved with the pattern to be printed and covered with the fluid (ink) from a reservoir underneath the roll. As the roll is filled with fluid, air bubbles may be included in the liquid [2, 3]. Then the substrate (carried on a web) is pressed against the engraved roll with the use of a rubber backing roll. As the substrate and roll are separated, a liquid bridge is formed which is stretched and broken, pulling liquid out of the cavities and onto the substrate. The air bubbles merge to form an air column. The amount of ink transferred from the supply surface to the printed surface is totally governed by the wetting/dewetting dynamics and the speed of the process [4].

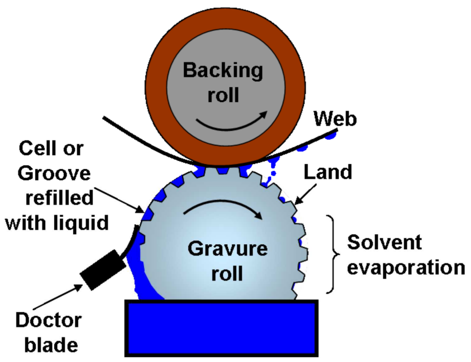

Figure 1: Schematic of Gravure apparatus

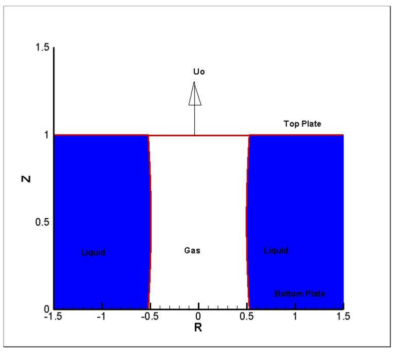

Figure 2 : The model of the simulation

In this work a computational model is developed in order to study the transfer of liquid having a gas inclusion from a stationary to a moving plate using an axisymmetric liquid bridge as a model system. We consider a Newtonian liquid, enclosed between two axisymmetric horizontal plates. A gas bubble is included in the liquid around its axis of symmetry. Initially the two plates are stationary and the bubble touches both surfaces (Figure 2). Then the upper surface is pulled upwards with constant velocity. As the surface is moving the liquid is stretched until it breaks. During this stretching of the liquid the gas bubble is split in two smaller bubbles. The Galerkin FEM is used to solve the governing equations, and elliptic mesh generation [5] is used to track the position of the interface as it evolves in time. To account for differences in surface wettability between the two plates, the contact line is allowed to slip along the plates with a different dynamic contact angle, while imposing the Navier-slip law to relieve the stress singularity that develops near the moving contact lines. The steady Stokes equations are solved, with time dependence entering the problem through the kinematic boundary condition.

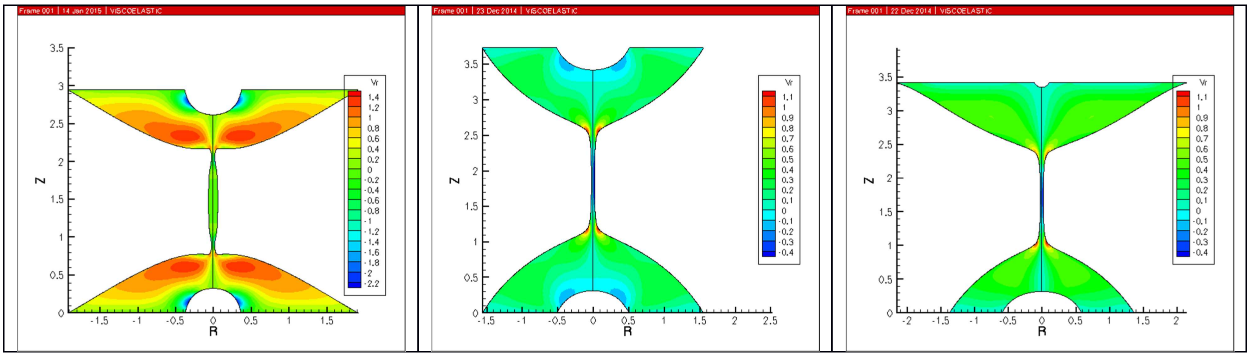

Figure 3: Liquid bridge breakup between a) two Delrin surfaces (left) b) two LDPE surfaces (middle) c) a hydrophilic on top (Delrin) and a hydrophobic on bottom (LDPE) surfaces (right).

From the results obtained (Figure 3) it is evident that when both surfaces are of the same material the liquid tends to merge at the center of the bridge, causing the gas to separate into two bubbles of approximately equal volume, and pushes the two bubbles towards the surfaces. Considering a constant pulling velocity the time passing until the liquid bridge break up (and consequently the maximum length of the bridge) is inversely proportional to the surface tension. When the two surfaces are of different materials the contained gas moves primarily towards the most hydrophobic surface. Thus in a printing process wettability difference can be used in order to transfer gas bubbles enclosed by the coating away from the printed surface.

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