Emptying of Gravure Cavities Containing Shear-thinning and Shear-thickening Liquids

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Extended Abstract

One technology widely used for creating uniform coatings on a large scale is roll-to-roll gravure, which involves emptying of liquids from micron-scale cavities to a second surface. Although coating liquids containing functional additives usually exhibit non-Newtonian rheological behavior, fundamental understanding of the influence of liquid rheology on liquid transfer is still lacking. To address this issue, two-dimensional numerical simulations are used to study liquid emptying from a model configuration. In this configuration, liquid is confined between a stationary trapezoidal cavity and a horizontal substrate above the cavity. Liquid is driven out of the cavity by a combination of horizontal substrate motion and an imposed pressure gradient. Liquids exhibiting rate-dependent rheology described by Carreau-type expressions are considered, inertial and gravitational effects are neglected, and the nonlinear governing equations are solved using the Galerkin finite-element method. For Newtonian liquids, it is found that the fraction of liquid left in the cavity, $V_r$, collapses onto a master curve with three regimes distinguished by the relative strength of the driving forces aiding contact-line motion (surface-tension forces and imposed pressure gradient) and the resistance hindering contact-line motion (viscous forces). In the first regime, there is strong contact-line motion and $V_r$ is highly dependent on surface wettability. In the second regime, $V_r$ is characterized by a power-law relationship similar to that observed for liquid-film withdrawal. In the third regime, $V_r$ approaches a plateau and the influence of surface wettability vanishes. This master curve with distinct regimes is also observed for

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shear-thinning (shear-thickening) liquids. Shear-thinning (shear-thickening) is found to improve (worsen) cavity emptying compared to the Newtonian case by aiding (hindering) contact-line motion through reduced (enhanced) viscosities.