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

Jyun-Ting Wu,[1] Marcio S. Carvalho,[2] and Satish Kumar[1]

[1]*Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota 55455, USA*
[2]*Department of Mechanical Engineering, Pontificia Universidade Catolica do Rio de Janeiro, Rio de Janeiro, RJ, 22451-041, Brazil*

ISCST-20180918PM-A-PD4

Presented at the 19th International Coating Science and Technology Symposium, September 16-19, 2018, Long Beach, CA, USA†.

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

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.