



Contribution

# Filling and Emptying of Gravure Cells - A CFD Analysis -

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## 1. Introduction

Gravure roll coating is commonly used where low coat weights are to be applied at high speed. In such situations, roll coating can be problematic because the coat weight is sensitive to the intricate balance of viscous, capillary and inertial forces within the roll gap. Slight changes in speed or roll gap can drastically affect the final coating thickness when the desired coat weight is small. With gravure rolls, much of the coating fluid is contained within the gravure cells, which is a fixed volume for each roll. Therefore, the final coat weight is less a function of less-controlled parameters (fluid viscosity, surface tension and roll speed) and more a function of the cell geometry, which can be finely controlled for each application.

In gravure roll coating, the key to understanding how the cells fill and empty is to study the processes occurring within individual cells. This is very difficult to do experimentally because of the minute size of the gravure cells: they are typically less than  $100\mu\text{m}$  across. Also, the speed at which a gravure roll rotates (typically

visualization virtually impossible. Therefore, little study has been done of the cell filling and emptying of individual gravure cells. Schwartz<sup>1)</sup> presented a numerical model of the gravure cell withdrawal process; this work did not include effects of entrapped air within the cell or the effects of inertia.

In this paper the numerical fluid flow model is based on a finite-control-volume technique. This method does not impose specific flow values at any point (such as along contact lines and no-slip boundaries), but rather keeps track of the mass and momentum in each control volume element. The locations of fluid interfaces are tracked by a volume-of-fluid (VOF) method in which the fluid fraction within each mesh cell is tracked and stored. Using the fluid fractions of neighboring cells, free surfaces can be located, and surface slopes and curvatures can be computed<sup>2)</sup>. Newtonian fluid properties were used for all simulations presented in this paper.

At contact lines, an additional force describing the adhesion between the solid and the liquid is added along with the dynamic

conservation. This adhesion force is assumed to arise from molecular interactions between the solid and liquid. The interaction is characterized by the static contact angle because the molecular processes that cause the adhesion force act at a space and time scale far smaller and faster than those of the flow process. Therefore, the wall adhesion force is computed from the cosine of the static contact angle and the interfacial tension between the air and the liquid<sup>3)</sup>.

In the gravure coating process, air can become trapped. In this model, the trapped air behaves isentropically with PV<sup>1.4</sup> held constant to control the pressure-volume relation for regions with trapped gas. There is no transfer of energy or mass between the fluid and the gas bubble. In open gas regions, the gas pressure is fixed to be atmospheric.

All of the simulations presented here were computed using this combined control-volume-VOF method as it has been implemented in the commercial software package FLOW-3D<sup>®</sup> developed by Flow Science, Inc., Santa Fe, New Mexico, USA<sup>4)</sup>.

