COATING PROCESS OF PHOTOSENSITIVE CYLINDERS

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Abstract. Photosensitive cylinders are used in printing arts and more particularly in electrophotographic printing (xerographic copy). The photosensitive coating is applied to the cylinder in liquid form, before it is solidified. The liquid is applied to the cylinder through a needle applicator that translates along the direction of the cylinder axis. The cylinder rotates during this process in order to cover the entire surface. Therefore, the liquid is applied in a spiral pattern. To help spread liquid over the cylinder surface and improve the thickness uniformity, each liquid stream applied from the needle passes under a flexible blade. This process leads to a coating that presents a spiral pattern on the deposited layer thickness, which can cause defects on the electrophotographic process. The complete understanding of the flow is vital to the optimization of the process.

A theoretical model of the thin film flow over the surface of a rotating cylinder is presented here. It is based on the lubrication approximation considering a thin precursor film in front of the apparent contact line. The resulting non-linear fourth-order PDE for the film thickness was solved by second-order finite difference method. The time discretization was done by using implicit Crank-Nicholson scheme. The non-linear algebraic equation at each time step was solved by Newton's method. The results show how the uniformity of the deposited layer varies with process parameters and liquid properties.

Keywords: Liquid thin films, contact line, free boundary problem, finite difference method.

1. Introduction

Photosensitive cylinders are used in the printing art and more particularly in Electrophotographic Printing. The coating is applied to the cylinder by rotating it about its longitudinal axis and applying the liquid from an applicator in a spiral pattern as shown in Fig.1. This process may lead to a non-uniform thickness profile on the roll surface if the operating parameters are not properly chosen. As in many other coating applications, the challenge to obtain a uniform liquid layer thickness as fast as possible.

The goal of this research is to develop a theoretical model in order to better understand how the different parameters affect the uniformity of the liquid layer produced by liquid stream applied from a needle that is deposited on a rotating cylinder by the process described above.

The 3-D transient liquid flow is modeled using lubrication approximation and the appropriate boundary condition at liquid-air interface. The Navier-Stokes equations are simplified into a fourth-order partial differential equation that describes how the liquid layer thickness varies with time and position.

Development of this complex theoretical model has been made by step (Fig.2). First, the thin film flow over an inclined plane with two feed ports was analyzed, the goal was to study how two liquid streams originated from the feed ports merges and flow down the plane. The second step corresponded to the one-dimensional analysis of a thin film over a rotating cylinder. The goal was to study how the viscous drag from the roll rotation, surface tension forces and gravitational forces affect the thickness profile along the azimuthal direction. The last step, reported here, is the

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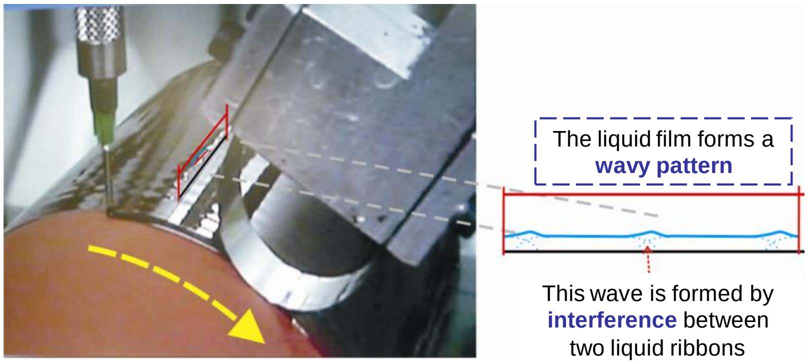
combination of the two previous one, and will correspond to the complete two-dimensional thin film flow over a rotating cylinder with a moving feed port.



The liquid film forms a **wavy pattern**

This wave is formed by **interference** between two liquid ribbons

Figure 1. Coating process of photosensitive cylinder.

2. Three-Dimensional Film Flow on rotating horizontal cylinder with moving Feed Ports

The liquid is applied to the cylinder through a needle applicator, of radius R_f, which translates along the direction of the cylinder axis at constant velocity V_{step}. The cylinder of radius R is rotating about its axis of revolution at constant angular speed Ω. The axis is held perpendicular to gravity g. In addition to the gravitational force, viscous and capillary forces are potentially important in this flow. The liquid is assumed to be an incompressible and Newtonian and completely wets the cylinder. It is subject to a no-slip boundary condition at the moving wall and force balance and kinematic conditions on the moving free surface.

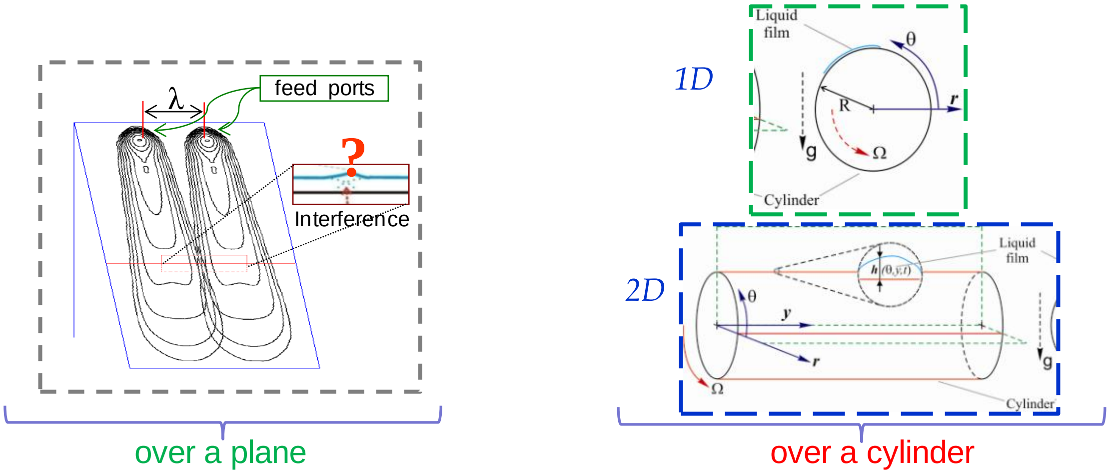


Figure 2. Steps on the development of the theoretical model.

In practical coating applications, the layer thickness is always very small $h/R<<1$, which allows a simplified analysis based on the lubrication theory (Weidner et al, 1997 and Evans et al, 2005). With the classical simplifying assumptions of the lubrication theory we have the dimensionless evolution equation for the coating thickness, $h(\theta,y,t)$.

$$\frac{\partial h}{\partial t}+MW\frac{\partial h}{\partial \theta}-\frac{\partial}{\partial \theta}\left(\frac{h^3}{3}\cos\theta\right)+\nabla\cdot\left\{\frac{h^3}{3Bo}\nabla(h+\nabla^2\mathrm{h})+\frac{h^3}{3}[W^2-\sin\theta]\nabla h\right\}+W_\Gamma(\theta_{\mathrm{cp}},\mathrm{y}_{\mathrm{cp}}(\mathrm{t}))=0$$

The behavior of the coating is determined by four parameters: M, W, Bo and W_Γ ($M=\frac{\mu}{\rho\sqrt{gR^3}}$,$W=\frac{\Omega}{\sqrt{g/R}}$, $Bo=\frac{\rho g R^2}{\sigma}$)

Where Bo represents the Bound number, W^2 represent the dimensionless rotation rate and MW is the ratio of the wall speed $R\Omega$ to the velocity scale U ($U=\rho g H^2/\mu$), where H is the characteristic thin film thickness).

The liquid feed port is adding an extra term to the equation that represents the liquid injection. Here W_Γ is the injection velocity normal to the cylindrical surface (see Schwartz, 1988). Liquid is injected with a parabolic velocity profile through a circle of radius R_f, centered in the point (θ_{cp}, $y_{\text{cp}}(t)$) which is changing along the time at fixed θ_{cp} position. Thus,

$$W_\Gamma = \begin{cases} \dfrac{2\Gamma}{\pi {R_f}^2}\left[1-\left(\dfrac{r}{R_f}\right)^2\right]; & r \leq R_f \\ 0 \quad ; & r \leq R_f \end{cases} \qquad where, \qquad r = \left[\left(\theta-\theta_{cp}\right)^2 + \left(y - y_{cp}(t)\right)^2\right]^{1/2}$$

Γ is the volumetric feed rate.

Due to the well-known contact line paradox (macroscopic divergence of the viscous dissipation rate), theoretical and computational methods require some regularizing mechanism. There are two different approaches in the literature. One possibility is to relax the no-slip boundary condition at fluid–solid interface, introducing a slipping length l_s. The other approach is to assume the existence of a thin precursor film h_f ahead of apparent contact line. Diez, Kondic and Bertozzi (2001), made an extensive comparison of these regularizing mechanisms. The main conclusion of these studies was that the precursor film model produced equivalent results to slip models when $h_f = l_s$. Because the computational performance of the precursor model is much better, we use this approach in this work.

2.1 Initial and boundary conditions

The initial condition is just $h = h_f$ at $t = 0$. In the θ direction, the coating is required to be periodic: $h(\theta=0,t) = h(\theta=2\pi,t)$ this implies $\frac{\partial h}{\partial \theta} = \frac{\partial^3 h}{\partial \theta^3} = 0$ at $\theta = 0, 2\pi$; and at the end surface $y = 0$ and $y = \text{L}$, zero flux boundary condition are imposed: $\frac{\partial h}{\partial y} = \frac{\partial^3 h}{\partial y^3} = 0$.

3. Numerical solution

The equation showed above is a fourth-order, non-linear partial differential equation. This equation and its initial and boundary conditions were discretized using finite-difference approximations. The discretization used here is the second-order scheme proposed by Diez and Kondic (2002). Because the precursor film thickness is very small and the derivatives near the apparent contact line very high, discretization errors may lead to negative values of the film thickness. It is important to use a positive preserving scheme (PPS) in the finite difference discretization.

The time discretization was done by a Crank-Nicholson scheme. The resulting non-linear set of algebraic equations was solved by the aid of Newton's method. A linear extrapolation of the two previous solution is used to calculate the initial guess and the time step is adjusted such that the number of Newton’s step remains inside a given range.

4. Validation and Results

Our numerical method was validated by comparing the prediction of Rayleigh-Taylor instabilities in a stationary cylinder presented by Weidner et al. (1997) who considers the Rayleigh-Taylor instabilities. The instability leads to the formation of drops at the cylinder underside, which is supported by surface tension.

The effect of the feed port velocity on the thickness profile is present in fig. 3. It is clear that the speed needs to be related to the rotation speed of the cylinder in order to obtain a full coverage.

Figure 4 shows the thickness profile obtained at $Bo = 0.1$, $M = 0.007$, $W = 3.0$, $R = lc$, $R_f = 0.25$, $h_f = 0.0007$, $\Gamma = 1.0\text{e-}3$, $V_{step} = 1.0\text{e-}3$.

The method presented here is going to be extended to include the change in viscosity due to the solidification process that occurs during the application.

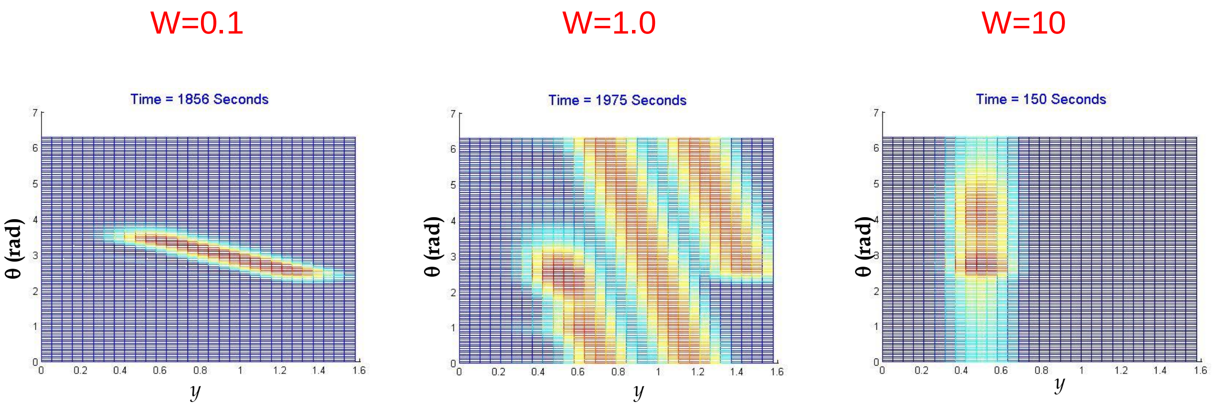


Figure 4. Non-stationary cylinder with injection with moving feed port.

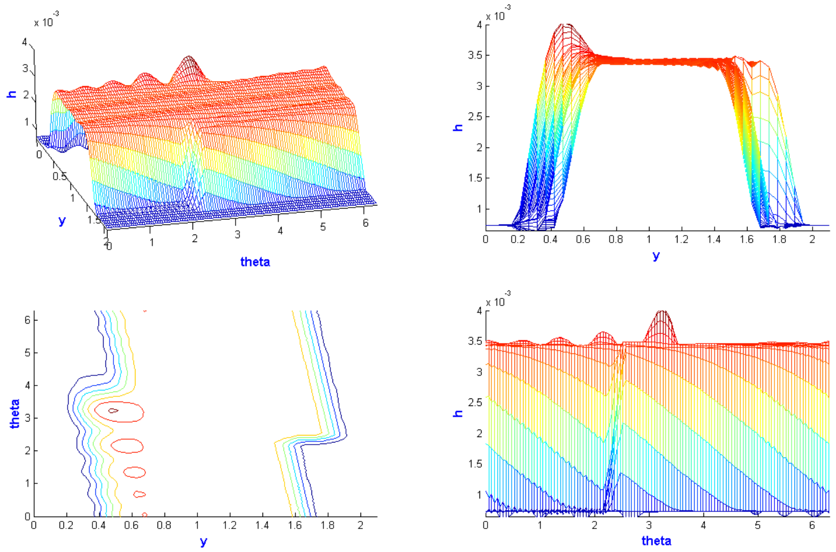


Figure 5. Coating thickness over a cylinder.

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