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Reverse Roll Coating Flow with Non-Newtonian Fluids

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Abstract. In this study an incompressible flow with non-Newtonian fluids in the reverse roll coating process was investigated. Non-Newtonian behavior of the coating fluid was accounted by using power law model with power index, n, ranging from 0.8 to 1.2. Effect of roll speed ratio (V_2/V_1) of the panel roll to the applicator roll and gap distance on the coating film thickness were also investigated. Numerical results were in good agreement with those of experimental data within 15%-20%. Results indicated that the film thickness ratios are function of power-law index, roll speed ration and ratio of roll radius to gap distance. The equations for film thickness ratio were obtained from numerical results as shown below:

$$\frac{t_2}{t_1}=0.89n^{0.55}\left(\frac{V_2}{V_1}\right)^{-0.83}\left(\frac{H_0}{R_m}\right)^{0.0025}, \qquad \frac{t_3}{t_1}=65.6n^{0.0014}\left(\frac{V_2}{V_1}\right)^{-0.043}\left(\frac{H_0}{R_m}\right)^{0.624},$$

where t_1, t_2 and t_3 are inlet film, transferred film and leakage film thickness, respectively, n is power-law index, V_1 and V_2 are roll speed of applicator roll and panel roll, R_m is average radius of two rolls and H_0 is gap distance. The correlations are accurate within 10% for $0.8\le n\le 1.2$, $0.5\le V_2/V_1\le 2$, and $7.7\times 10^{-5}\le H_0/R_m\le 1.54\times 10^{-4}$.

AMS subject classifications: 76A05

Key words: Reverse roll coating, non-Newtonian flow, power-law.

1 Introduction

Roll coating is a process by which a thin liquid film is formed on a continuous web or substrate by the use of two or more rotating rolls. This process can be used to produce a wide variety of finishing products. The nip distance between the two rotating rolls is much smaller than the rolls radii and when a fluid flows through such a small gap, it

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comes out as small liquid film, which can be used to coat on a surface. The fluid flow in a small gap between a pair of rotating rolls is the primary factor controlling the thickness and uniformity of the coated film. The thickness of the coating depends primarily on the gap between adjacent rolls and their relative speeds. Depending upon the direction of rolls, roll coating is classified as forward roll coating and reverse roll coating. In forward roll coating, the roll surfaces move in the same direction and in reverse roll coating they move in opposite direction.

Reverse roll coating is an important and common industrial technique widely used to coat magnetic media, adhesive tape, films, foils and coated paper [1,2]. Great advantage of a reverse roll coater is its ability to produce uniform wet films as thin as 25 μm or less at speeds of up to 5 m/s. The liquid may be Newtonian, but more often it is not; such as is the ease for adhesives, paints, or magnetic suspensions. It is also capable of handling liquids of a wide range of viscosity. This makes it an important method of high-speed precision coating.

Over the past five decades, extensive investigations have been carried out to address the flow problems of roll coating processes though experimental, analytical and computational approaches. Early works on reverse roll coating were reported by Ho and Holland [3] and Greener and Middleman [4]. They used lubrication theory to investigate reverse roll coating systems, ignoring the effects of surface tension, the presence of free surfaces and dynamic contact lines. Coyle *et al.* [5] presented a detailed theoretical analysis, along with supporting experiments, which together provide a good description of the operation of a reverse roll coater. The flow in the metering gap of a reverse roll coater was examined by finite element solutions of the Navier-Stokes equations. The results showed that at high speed ratios and capillary numbers, the metered film flow deviated strongly from predictions of lubrication theory. The wetting line moves through the gap center and the metered film thickness passed through a minimum.

Coyle *et al.* [6] presented a simple model of reverse roll coating considering the fluid dynamics of coating flow. The results indicated that the film-transfer free surface and the recirculation under it did not significantly influence the flow rate through the gap. Deviations from lubrication theory occurred only under conditions of low speed ratio and large gap when the effect of gravity became appreciable. Hao and Haber [7] continued the work to study wide ranges of operating conditions that were of practical importance. They used the Galerkin finite element method of solution formulated by Coyle *et al.* [6] to analyze the coating flow problem.

Chandio and Webster [8,9] used finite element modeling to predict the flow associated with the reverse roller-coating of alloy sheets using a protective film of solvent-based lacquer. A finite element simulation of the roller-coating process was presented, based on a semi-implicit Taylor-Galerkin/Pressure-correction algorithm. A mathematical model was derived to describe the solvent coating applied to the underside of the sheet, assuming that the lacquer is a Newtonian fluid. The effects of increasing foil and roll-speeds on characteristic flow quantities such as pressure, lift, drag and shear-rate were reported. At increasing roll-speeds, pressure and lift on the foil display a linear decreasing trend;