Two-layer Slot Coating Frequency Response for Active Control

Takeaki Tsuda,[*1] **Juan M. de Santos**[*2] and **L. E. Scriven**[*2]

[*1] Integrated Manufacturing Technology Laboratory, Dai Nippon Printing Co., Ltd.
1-1-3, Midorigahara, Tsukuba, Ibaraki, 300-2646, Japan

[*2] Department of Chemical Engineering & Materials Science
University of Minnesota, Minneapolis, MN 55455

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1. Abstract

Precise, rapid coating two layers simultaneously with a dual slot die is an established technology (e.g. Ishiwata et al. 1971, Sartor et al. 1996). However, interlayer diffusion can be deleterious; interlayer mixing by microvortices disruptive. Barring nonuniformities of unacceptable magnitude can be produced by back-up roll runout, feed pump ripple, air pressure ("vacuum") fluctuations, and substrate transport cogging that are impracticable to eliminate. Steady-state modeling by computational fluid mechanics reveals mixing, and is the precursor to frequency response analysis, an aid to understanding the nonuniformities and to designing active control to reduce them, as we reported about single-layer slot die coating at ISCST 2004. Here we report subsequent research on two-layer coating.

2. Interlayer treatment

A key issue is interdiffusion in the interlayer zone, which is not an interface (cf. Taylor & Hrymak 1997) yet has been approximated as one, though devoid of interfacial tension (e.g. Scanlan 1990, Cohen 1993, Musson 2001).

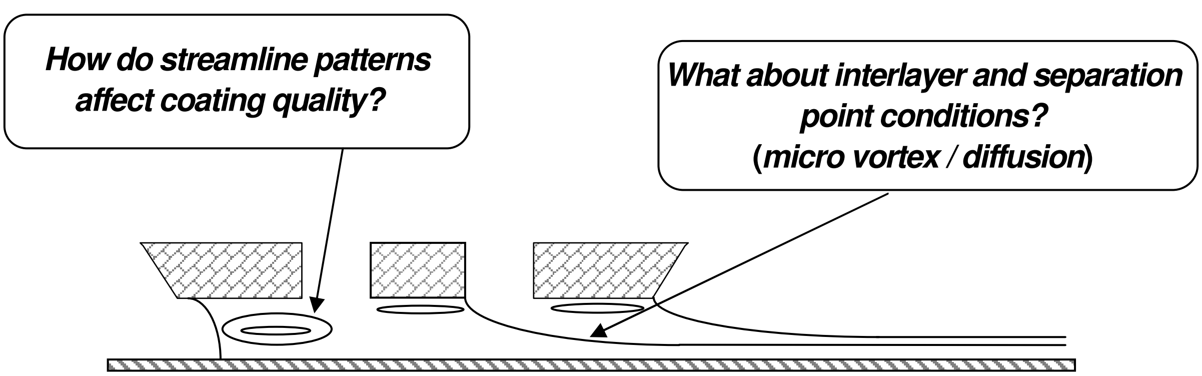
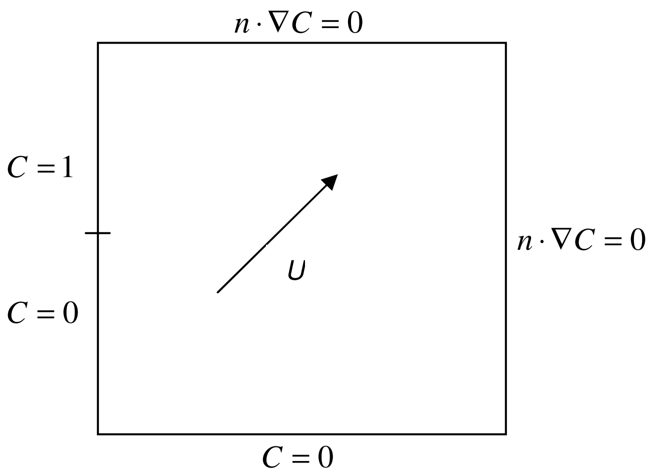


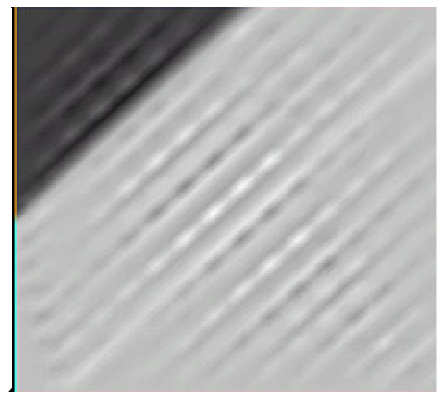
Fig. 1 Key issues in quality of two-layer slot coating.

3. Flow and transport model and method of solving the equations

So we solved a convective-diffusion equation system, along with the usual Navier-Stokes system and elliptic equations of mesh generation, for steady-state regimes, and linearizations for imposed small sinusoidal disturbances. We employed the Galerkin Finite Element Method for the Navier-Stokes system and, to avoid extraneous wiggles associated with high local Peclet number, the Streamline Upwind Petrov-Galerkin technique for the convective-diffusion system along with the separating streamline. The separation point on the die's mid-lip was assigned the arithmetic mean concentration between the layers and on each side of the separating streamline an adaptively graded mesh was individually generated that amply resolved the interlayer diffusion zone. The sequence of alternatives tested is shown in Fig. 2.



(a) Test Problem



(b) Galerkin Method

(c) SUPG

(d) Galerkin Least Square

(e) SUPG + Adaptive Mesh

Fig.2 The sequence of alternatives tested. Conditions: 961(31 x 31) Quadratic Basis Functions, Peclet Number, 10^5. The separation point is located at intersection of C=0 and C=1 in Fig. 2(a).

4. Analysis of steady states and frequency response

The steady-state results show that when the top layer invades the mid-gap region, its residence time in the turnaround flow there heightens interlayer diffusion; and that onset of microvortices there and in the top-layer feed slot can indeed greatly mix the layers. The frequency-response results illustrate how 2D flow fields make variation of thickness at outflow.

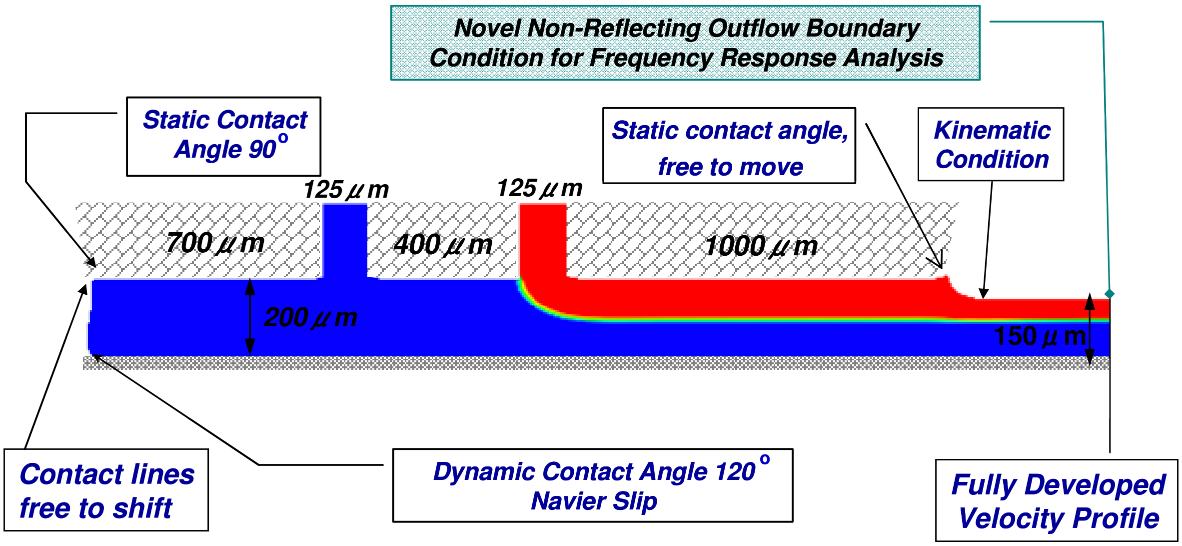


Fig. 3 Boundary conditions and a predicted steady state.

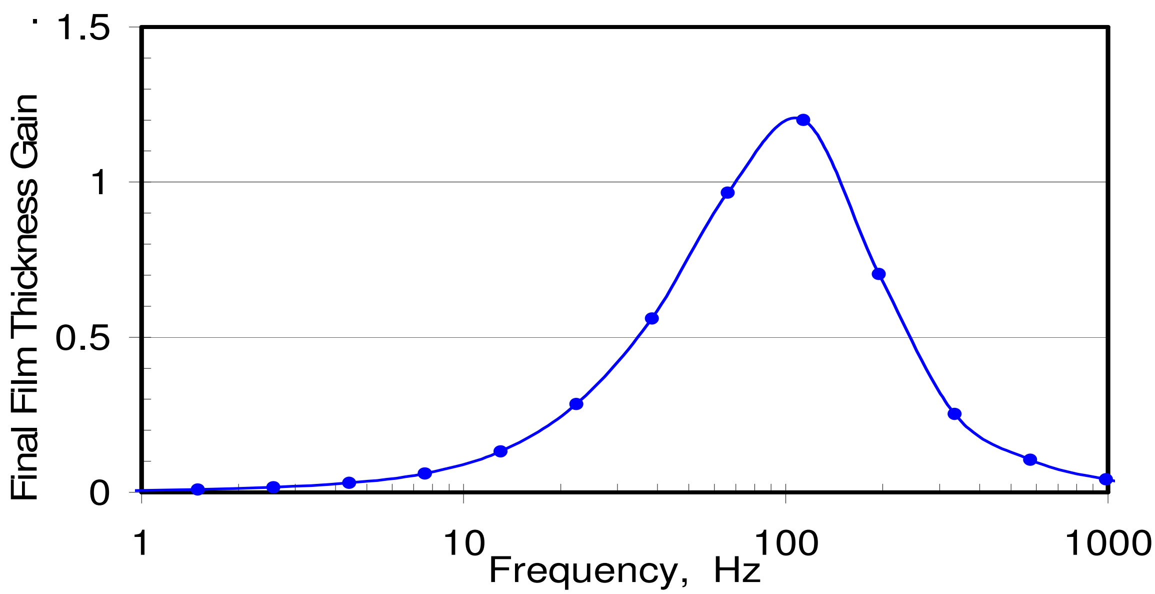


Fig. 4 Example of frequency response to coating gap oscillation. The web velocity is 50cm/s; both layers have the same density, 1.0 g/cc and the same viscosity, 0.5 P; at the top layer/air interfacial surface tension is 50dyn/cm; the vacuum pressure is 0 Pa; the film thickness ratio (upper to lower layer) is 0.5; the Peclet number is 10^5.

5. Active control

Besides frequency response to common disturbances, damping of dominant eigenmodes by active control was examined by solving the linear stability equation system without and with the equation of single-input sensing of a meniscus displacement and single-output control of flow rate. Fragmentary results indicate successful derivative control by choosing sensing point and gain on the basis of their effects on the damping coefficients of oscillatory normal modes, i.e. those whose eigenvalues have largest real parts.

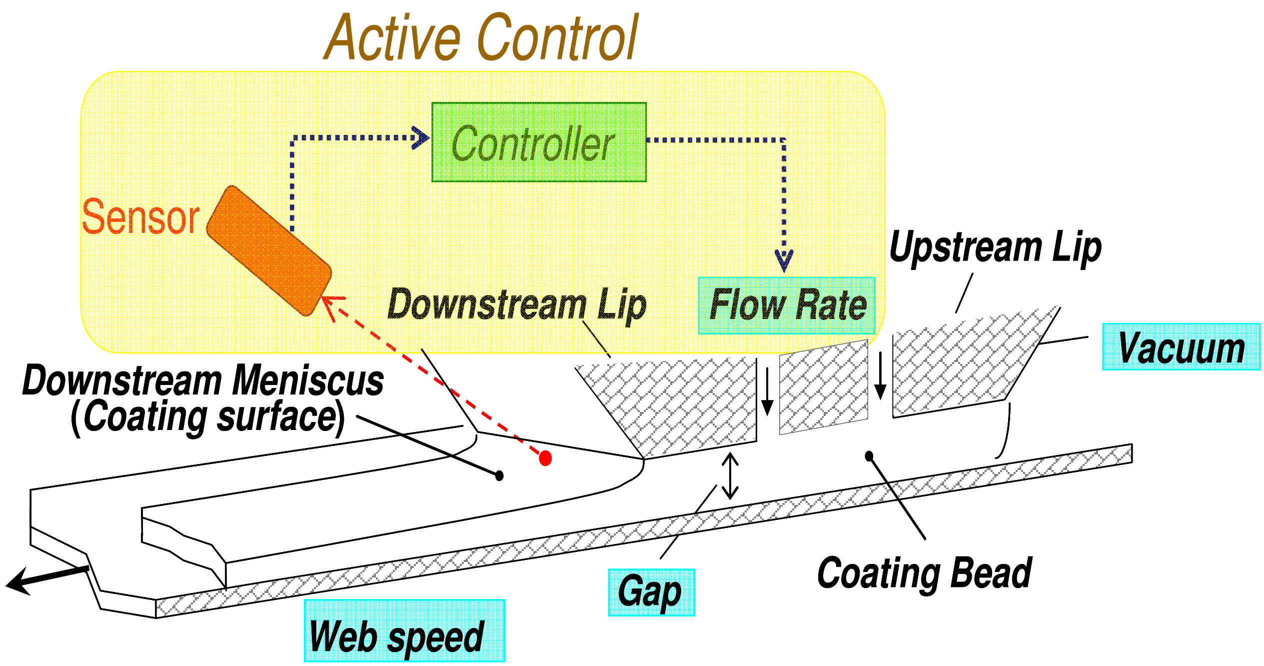


Fig. 5 Active control of two-layer slot coating flow

References

(1) Ishiwata, M., Nagai, Y. and Uchida, Y. 1971 US Patent 3584600. Fuji Photo Film Co., Ltd. Ashigara kamigun, Japan

(2) Sartor, L., Huff, S. and Kishi, C. 1996. International Patent Wo 9608319A2. Avery Dennison Corp, Pasadena, CA.

(3) Taylor, S. D. 1997 Two-Layer Slot Coating: Study of Die Geometry and Interfacial Region. Master's Thesis McMaster University, Hamilton Canada.

(4) Cohen, D. 1993 Two-layer Slot Coating: Flow Visualization and Modeling, M.S. Thesis, University of Minnesota, Minneapolis, MN.

(5) Scanlan, D. 1990 Two-Slot Coater Analysis: Inner Layer Separation Issue in Two-Layer Coating, M.S. Thesis, University of Minnesota, Minneapolis, MN.

(6) Musson, L. 2001 Two-Layer Slot Coating, PhD Thesis, University of Minnesota, Minneapolis, MN. Published by UMI, Ann Arbor, MI.