

Uncovering Slide Coating Window with Theoretical Modeling

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Slide coating is a method used for rapidly depositing multilayer of coating onto a moving substrate or web simultaneously. This method is commonly used in the manufacturing of photographic products, magnetic recording media, and optical films. Slide coating is a premetered coating method, in which the thickness of the coating is set by the liquid flow rate and web speed only and independent of the other operating parameters, making it the method of choice for precision coating. However, the nature of the flow in the coating bead and therefore the uniformity of the liquid layer deposited on the substrate can be affected by the other operating parameters. The region in the operating parameters of a coating process where the applied liquid layer is adequately uniform is referred to the coating window and that is the focus of this study.

Fundamentals of slide coating window, even for single-layer, are not completely understood. Incomplete slide coating windows with some of the modes of coating bead breakdown are described in Chen (1992) and Hens and van Abbenyen (1997). Mechanisms, however, have not been addressed and the effects of die-lip geometry have not been explored. In contrast, slot coating window is much better understood, mechanisms of bead breakdown have been identified (Romero et al 2004) and the effects of die-lip geometry have been studied (Gates 1999). Our goal is to gain a clear understanding of slide coating window in the same level as in the slot coating or even better. The approaches that we employ are theoretical modeling and flow visualization. This presentation covers the theoretical modeling aspect of the study while the flow visualization aspect is covered in a separate poster titled "Mapping Slide Coating Window via Flow Visualization".

In the theoretical modeling, we solve steady 2-D Navier-Stokes equation for free-surface flow. Our method of choice for solving the equation system is the Galerkin finite element method. This approach has been used by past researchers: Christodoulou and Scriven (1989) and Chen (1992), but due to the high computation cost and memory demands in the past, they made only a few excursions in parameter space and did not perform a systematic exploration. In particular, they

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limits. We extend their works by performing a systematic parameter study of the steady-state 2-D flow in slide coating process by continuation in different operating parameters. Our target is to determine the critical parameters that define operating windows in applied vacuum, coating thickness and coating speed as a function of liquid physical properties, gap width, and slide-web configuration.

The theoretical predictions of the vacuum limits shown in Fig. 1 indicate that the bead breakup is initiated at the upstream meniscus. As applied vacuum falls, the upstream meniscus moves downstream toward the die-lip edge and at vacuum pressure less than a critical value, invades the die-lip and destroys the coating uniformity by forming alternating dry and coated lanes known as rivulets. This is the low vacuum limit. Alternatively, as the applied vacuum increases, as shown in Fig. 2, the upstream moves further upstream toward the vacuum box and when the static contact line reach the end of the die-face, any increase in vacuum pressure creates liquid leakage and the premetering action is lost. This is the high vacuum limit. These bead breakup mechanisms at the vacuum limits are similar to the mechanisms of vacuum limits in slot coating.

At low flow limit or minimum thickness limit, the bead breakup is initiated from the downstream meniscus in two different mechanisms. At low capillary number regime, shown in Fig. 3, the breakup occurs due to the downstream meniscus invading the gap, similar as to what happen in slot coating. At high capillary number, shown in Fig. 4, the film thickness on the slide is thicker due to the higher flow rate such that the downstream meniscus can curve more without invading the gap. However, the meniscus cannot curve more without limit as the wave on the slide foot eventually touch the film on the web, a very unstable flow condition, and the coating bead will break.

The difference in the bead breakup mechanisms is responsible for the different trends of low flow limit in the low and high capillary number regimes shown at Fig. 5. At low capillary number regime, the minimum thickness increases as the capillary number or coating speed increases, which indicates that thinner coating can be achieved only at low speeds. At high capillary number regime, the minimum thickness falls as the capillary number rises, indicating that thinner coating can be achieved at higher speeds. Figure 5 also shows the region in the parameter space at which the flow does not present a recirculation attached to the top free surface, a condition that should be avoided.

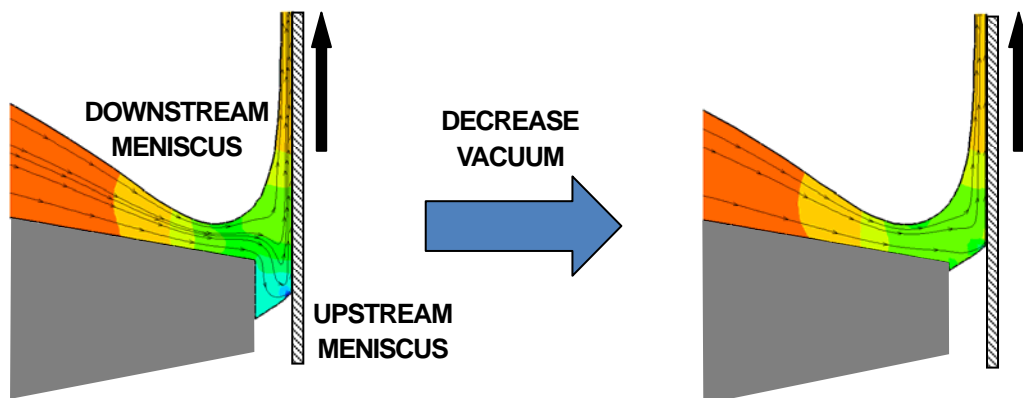


Figure 1 Bead Breakup Mechanism at Low-Vacuum Limit

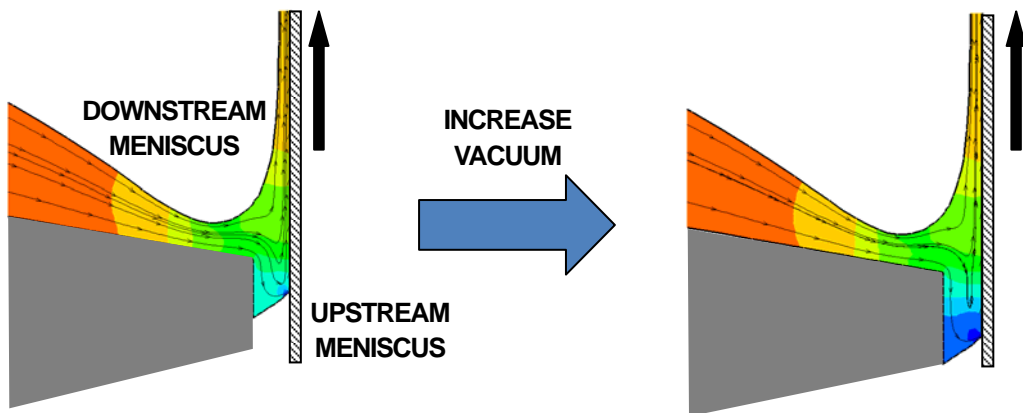


Figure 2 Bead Breakup Mechanism at High-Vacuum Limit

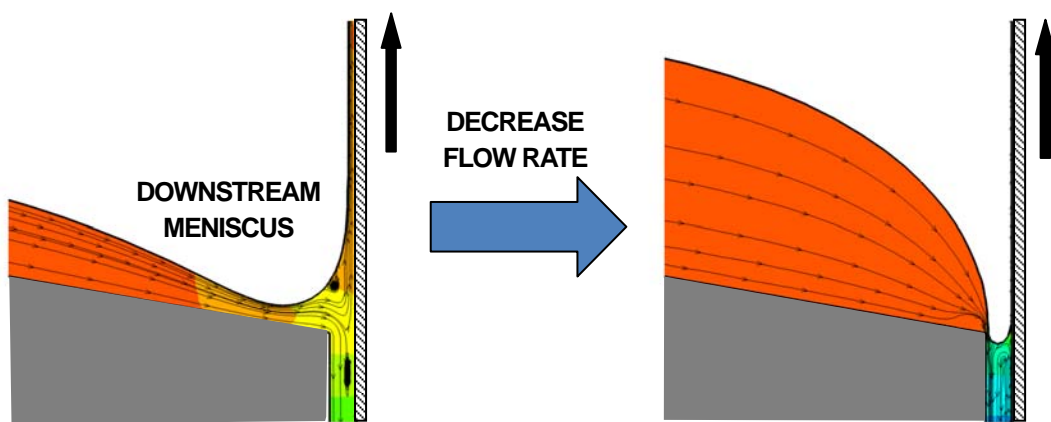


Figure 3 Bead Breakup Mechanism at Low-Flow Limit and Low Capillary Number Regime

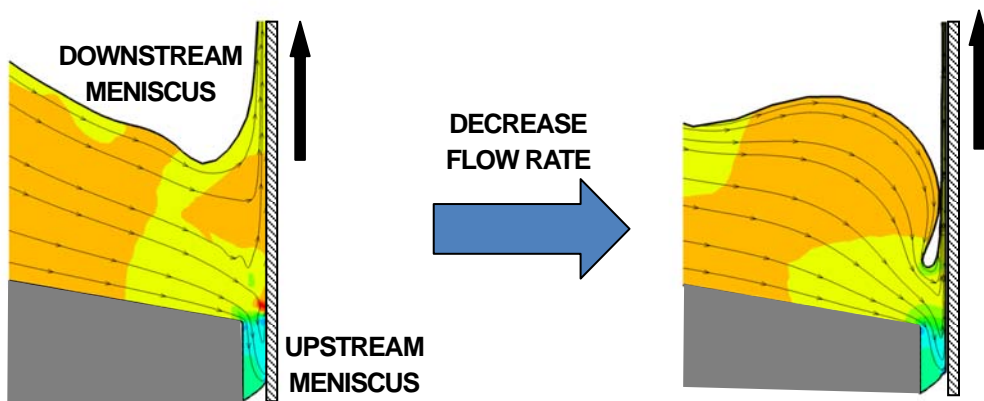


Figure 4 Bead Breakup Mechanism at Low-Flow Limit and High Capillary Number Regime

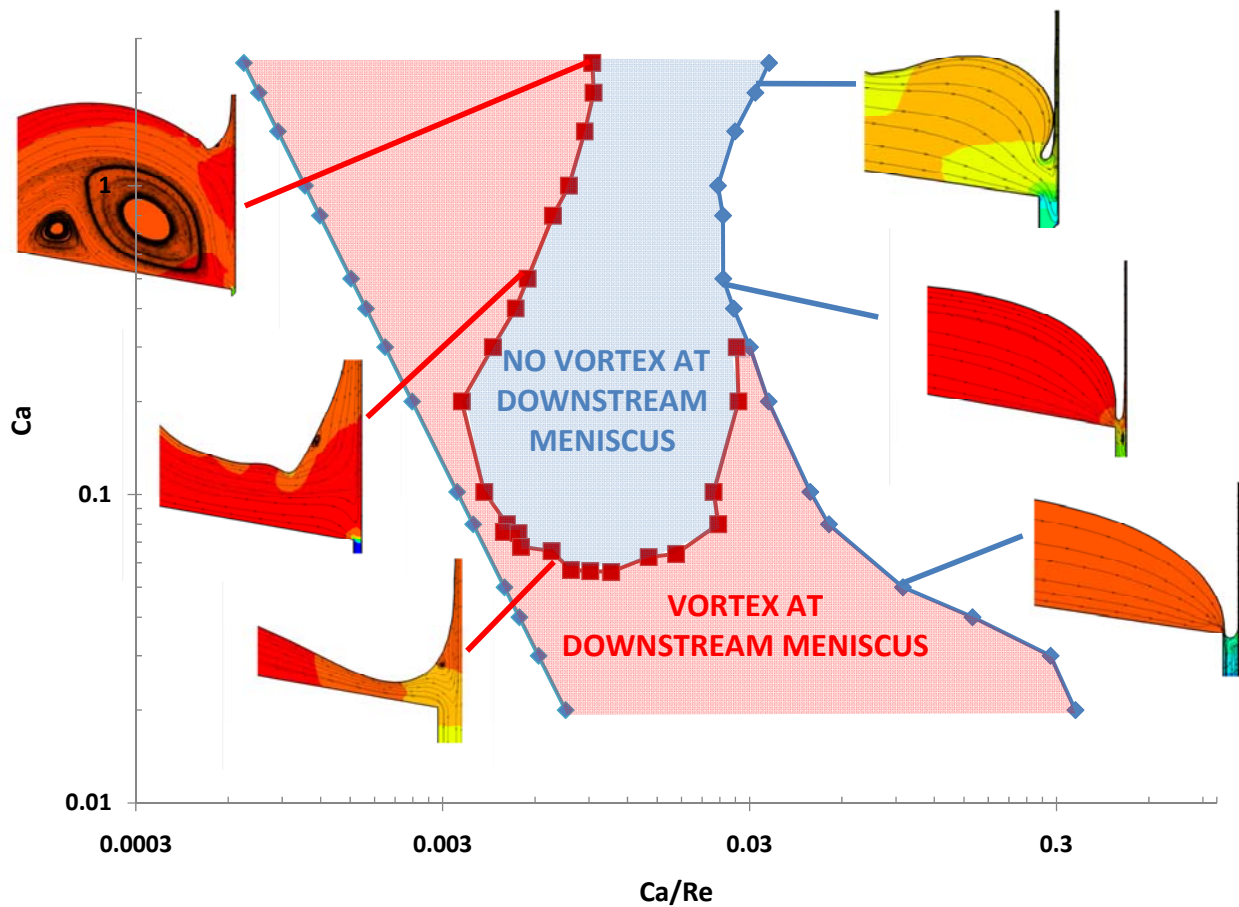


Figure 5 Slide Coating Window Prediction at Gap = 300 μm

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