Two-layer slot coating

Jaewook Nam*
School of Chemical Engineering, Sungkyunkwan university
(jaewooknam@skku.edu*)

Introduction

Typically, the slot coating process is designed for a single liquid layer. However, many products demand coatings consisting of two or more layers. To avoid multiple passes through the oven, all the different layers are coated before the solidification process starts. One possibility is to coat the layers simultaneously, in the same station, using a the dual slot coating. The uniformity of the surface that separates the two liquids, the interlayer, plays a crucial role on the final product quality. The interlayer initiates at a point located in the mid-lip, usually called the interlayer separation point. In order to minimize cross-web thickness variation and mixing of the two layer, the separation point should be located at the downstream corner of the mid-lip. As it moves upstream, the top layer invades the mid-gap region and dangerous turnaround flow and microvortices may appear. This phenomenon is called mid-gap invasion. We confirm the existence of the mid-gap invasion by visualization of the coating flow, reveal "invasion" mechanisms from Navier Stokes theory, and provide a simple criteria from examining a onset of critical flow state.

Methodology & results

Mid-gap invasion is studied experimentally by visualizing the coating flow. Since the size of the coating bead is small — in order of 100 micron — and coating liquids for each layer has different refractive index, it is almost impossible to visualize the bead from the side. Here, we use a glass backing roll to look the bead from inside the roll. The location of the interlayer separation point is marked by blue dye injected through the hole at the downstream shoulder of the mid lip.

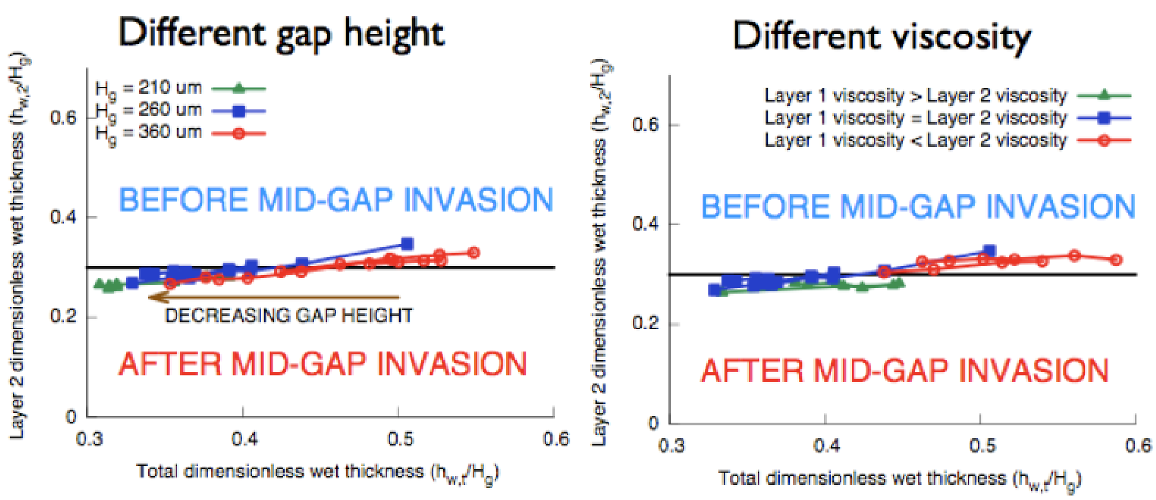

Figure 1. Critical bottom dimensionless layer flow rate versus total flow rate plots for different gap height and different viscosity ratio.

Near the critical flow rate, we always found a oscillation of the point along the mid-lip. The mid-lip vortex appears near the mid-lip also which enhances the mixing between two layers, and leads to coating defects. The mechanism behind the oscillation cannot be revealed by experiment because it moves so rapidly.

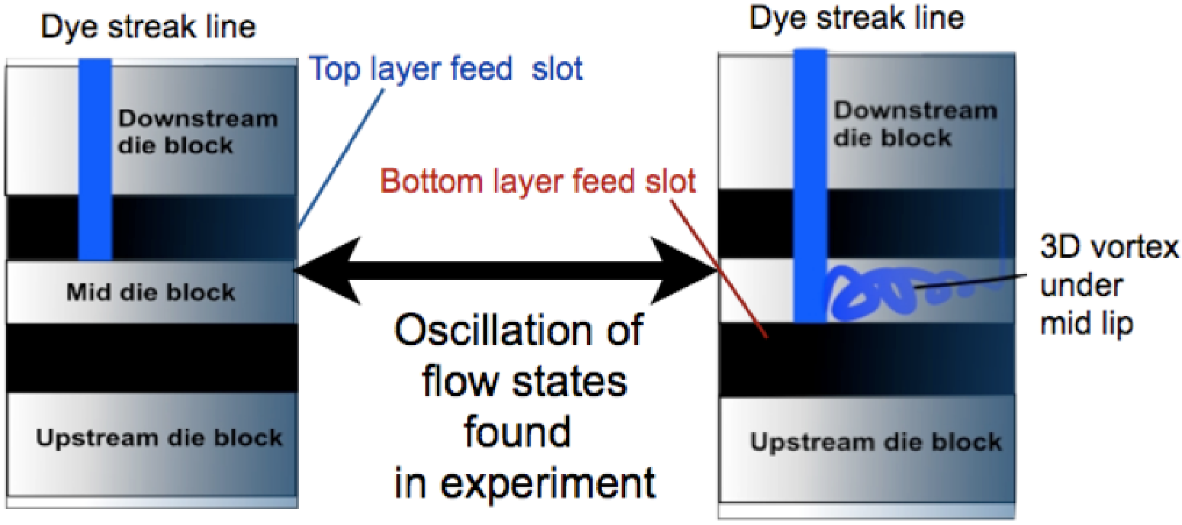

Figure 2. Oscillation of interlayer near the critical mid-gap invasion condition

With computer aided analysis on two dimensional incompressible free surface coating flow (Kistler and Scriven, 1984; de Santos, 1991), we was able to study the mechanisms behind oscillation. The velocity and pressure fields, and the interlayer separation location of steady state flow inside the coating bead are solved by Navier Stokes system in Galerkin finite element context. Computed solutions show different flow states for different viscosity ratio: the onset of turn-around flow occurs when the top layer is less viscous than bottom layer, the onset of vortex occurs when the top layer is more viscous than bottom layer.

In the onset of turn-around flow case, the interlayer separation point moves along the mid-lip, and reaches to the upstream corner of the mid-lip. The location of the point is extremely sensitive to the bottom layer flow rate near the critical condition. Therefore small flow rate fluctuation may lead to a large movement in the interlayer, i.e. oscillation.

In the onset of vortex case, the vortex occurs at the upstream corner of the mid lip near the critical condition. The size of vortex grow as the flow rate decrease. The separating streamline which contains vortex is very close to the interlayer near the critical dimensionless flow rate, 0.3. After merging of the vortex and the interlayer, the mixing zone of two layers is created under the mid-lip. Hence, the oscillation in this case means attaching and detaching of the vortex and the interlayer.

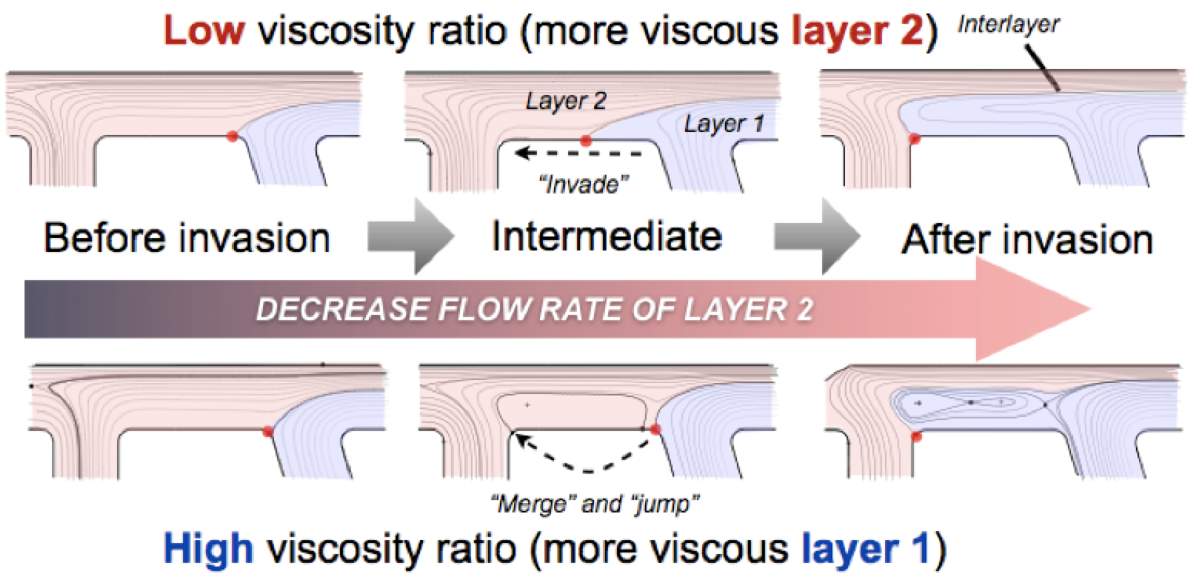

Figure 3. Oscillation of interlayer near the critical mid-gap invasion condition

Meanwhile, the flow field near the mid lip can be effectively modeled as a rectilinear flow. Even though this simple model cannot predict two different mechanisms compared with two dimensional G/FEM model, it yields a simple condition for the onset of mid-gap invasion condition: the inflection point of velocity profile at the mid-lip. This simple condition can be converted to the critical dimensionless flow rate condition, so called 1/3 rule. This condition supports the results from flow visualization and solution from Navier Stokes theory: mid-gap invasion occurs when the bottom layer thickness is less than the critical value and it is not a function of the other process parameters.

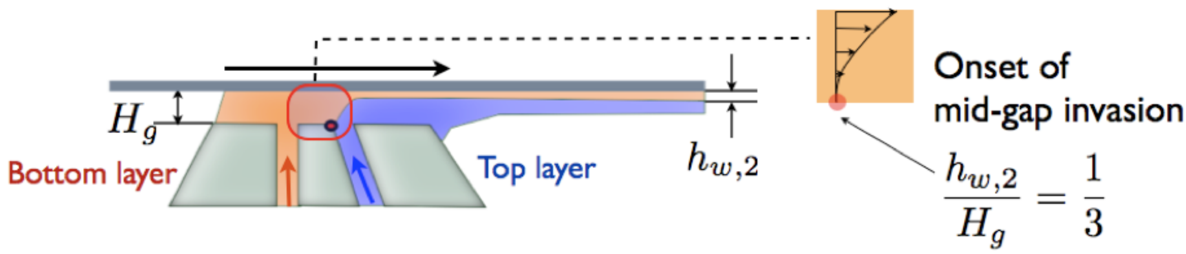

Figure 4. The simple mid-gap invasion condition.

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