SIMULATION OF THE WET-START PROCESS IN SLOT COATING

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Slot coating is widely used to make high quality coated products. Over the years, practitioners have steadily improved their techniques for increasing coating speed and reducing material waste. One technique is referred to as a wet start. Liquid flows out of the slot, accumulates at the exit, and then drips down under the action of gravity. The web and applicator are then moved together to initiate coating. Having a bead of liquid outside the end of the slot helps to insure a more uniform wetting of the web across the entire width of the slot. This, in turn, reduces the length of the initial, non-uniform portion of the coated material that must be discarded.

Although a wet start generally reduces the length of the startup transient, it does not eliminate the initial non-uniformity. For example, when the web first contacts the liquid bead, it may carry off a relatively thick layer of liquid because the initial bead is always larger than the bead existing during actual coating. Also, when the speed at which the web and applicator approach one another is too large, liquid in the initial bead will be forced over more of the external surface of the applicator, and more time may then be needed for the flow to thin down and reach a steady condition.

In this paper a set of powerful numerical techniques are used to study flows in slot

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coaters. A fixed-grid (FAVOR) and a volume-of-fluid (VOF) method are used to follow large deformations in fluid configuration associated with the startup process. A moving obstacle technique is used to move the web and applicator together. Finally, a grid-overlay method inserts results from an initial dripping-bead computation into a different grid having a moving web that initiates the startup process. The numerical techniques used in this paper are incorporated in a commercial software program ***FLOW-3D***®. A program description and extensive references can be found at www.flow3d.com.

For this study the fluid used is a non-Newtonian, shear-dependent fluid having a density of 1.0 g/cc, a dynamic viscosity at rest of 7.0 poise (and an asymptotic value at infinite shear of 0.4 poise), surface tension of 70.0 dynes/cm and a static contact angle of 40 degrees.

To initiate the wet start process, the slot coating applicator is separated from the web and fluid issuing horizontally from the slot is allowed to fall under the action of gravity. Figure 1 shows a cross section of the falling bead generated at the exit of a 0.05 cm slot having an inflow velocity of 7.54 cm/s. The bottom boundary of the computation has a continuative condition in which the derivatives of all flow variables normal to the boundary are zero.

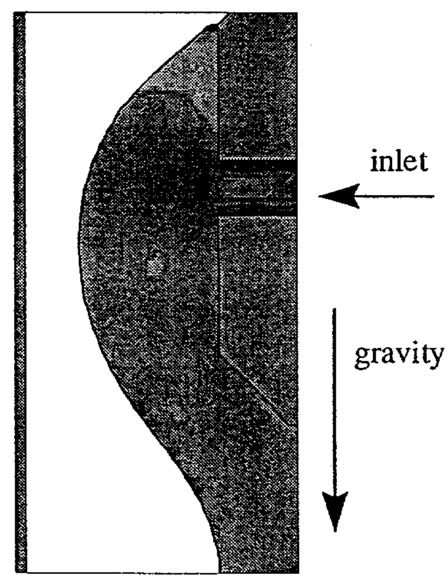

Figure 1. Initial Drip.

It is interesting to note that when fluid first exits the slot it protrudes out considerably further from the slot than in the steady-state configuration shown in Fig. 1. This happens because the bead is controlled by surface tension until there is sufficient fluid mass for gravity to over come the tension effects and draw the fluid downward. That is why the web at the left side of the frame appears so far away from the slot.

This bead is used as an initial condition for the coating process. The coating simulation begins with a new computational grid that includes a larger region in the direction of the translating web (upward in this case). The web is also been initialized in contact with the bead with a uniform velocity directed toward the slot, see the first frame in Fig.2. The web and slot move toward one another untl the desired stand off distance is reached. In our simulations the web has a coating (tangential) speed of 20.32 cm/s.

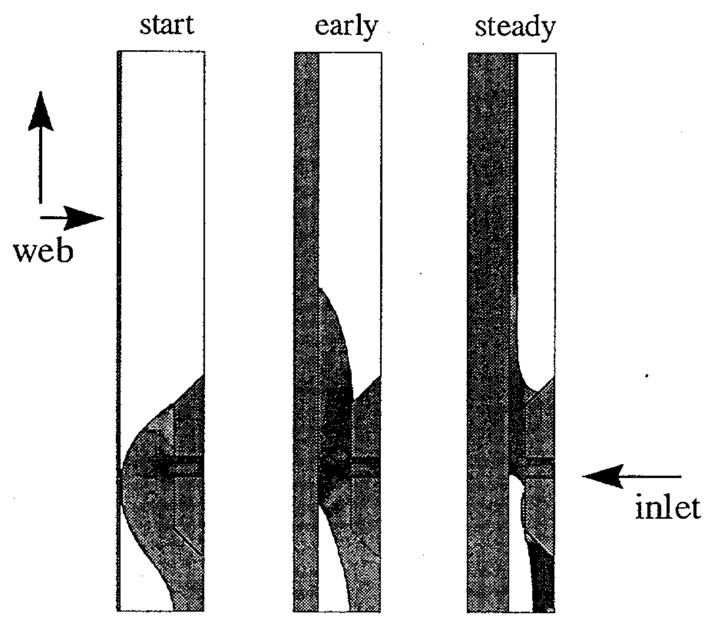

Figure 2. Wet starting a slot coater.

When the speed of gap closure between the web and applicator is 2.54 cm/s the initial bead is squashed between the web and applicator while at the same time it is being drawn up by the translating web. This combined squashing and stretching process is illustrated in frame 2 of Fig. 2.

The squashing is sufficient to eventually make coating liquid wet the top surface of the applicator, as can be seen in frame 3 of Fig. 2. When the speed of closure between the web and applicator is reduced this does not happen, the coating liquid separates from the applicator at the corner and a smoother start is recorded.

Because the initial, wet start, bead is much thicker than the distance between the web and applicator during normal operation (0.038 cm) the web carries off a thick blob of liquid at the beginning of the coating process. This is evident by comparing the thickness of liquid carried off by the web in frame 2 with that under steady conditions in frame 3 of Fig. 2.

This simulation exhibits several advantages of our numerical approach. For example, the fixed grid is evident because the web is modeled as an obstacle that moves through the grid from the left boundary toward the applicator (compare the changing shaded regions in the three frames of Fig. 2). An advantage of the VOF method can be seen in the early movement of the contact points on the web. The top contact point moves up with the web, but the lower contact point is initially moving downwards because of the squeezing of the liquid (frame 2 in Fig.2). Contact angles at the two contact points are not the same because of the differing dynamic conditions at these locations.

The computational time for this simulation is quite short (on the order of 1 hour on a laptop computer). This makes it easy to investigate the consequences of changing different operational parameters in order to optimize the slot coating start-up process.

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