Viscous heating Effects in Slot Die Coating

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Extended Abstract

When a fluid viscosity has an Arrhenius dependence on temperature, the possibility exists for a strong coupling between the thermal energy equation and the momentum equations due to viscous heating. A consequence of this coupling is that the relationship between shear rate and the pressure gradient can have a characteristic S-shape dependence. If the pressure gradient is the controlling parameter there may be a multiplicity of flow rates for a given pressure gradient, that may lead to hysteresis effects, and coating bead break-up. An example of this multiplicity behavior is illustrated in Figure 1 where the Brinkman number Br (a dimensionless flow rate) is plotted against the dimensionless pressure gradient λ for rectilinear Poiseuille flow in a a channel. As is evident in the figure, if the flow rate Br is the controlling parameter, then there is a unique pressure gradient for a specified Br. On the other hand, if the pressure gradient is the controlling parameter, then there may be a multiplicity of flow rates for a given λ. The S-shape curve suggest further that hysteresis effects are possible. Consider the case when λ is systematically increased from point *a*. When the turning point at *b* is reached any further increase in λ causes the flow system to jump to point *d*. Likewise, if the flow system is at point *d* and the process is reversed, i.e., λ is decreased until the turning point at *c* is reached, then the flow rate drops to *a* with further decrease in λ . A similar S-shape curve occurs in plain Couette flow when the dimensionless pressure gradient is replaced with the wall shear rate.

In this presentation we will examine theoretically and numerically how viscous heating effects of a Carreau-type coating liquid modify the operability bounds for a slot coater, modeled as a 1-D viscocapillary system. Viscous heating effects are analyzed in three representative slot die geometries: standard, overbite, and under bite configurations. The effects of viscous heating are accounted for

through an appropriately defined Brinkman number. We also show that the physics behind the hysteresis effect is related to an imbalance of heat generated in the coating bead due to viscous dissipation and the ability for that heat to be conducted away through the die/web surfaces.

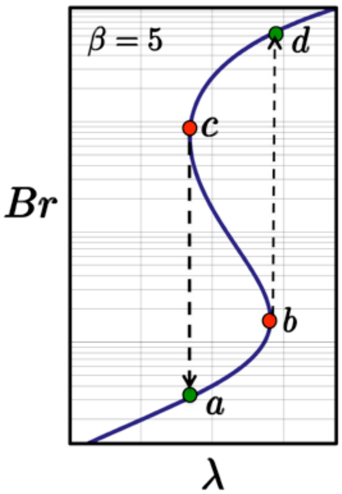

Figure 1: Variation of the dimensionless flow rate (Br) versus the dimensionless flow rate for plain Poiseuille flow with an Arrhenius viscosity model. The parameter β is the activation energy for the Arrhenius viscosity model.