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Influence of rheology and geometry on the teapot effect of a curtain coater

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Abstract

Curtain coating is a premetered coating method that becomes increasingly attractive in many application areas such as for instance paper coating, coating of construction parts, adhesives tapes, etc. Among the key advantages of curtain coating are low strain of the substrates, application of thin films at high web speeds and the application of multiple layers in a single step.

Slide-fed coating dies are commonly used for curtain coating, especially for multilayer coating. The coating fluid forms a liquid film that flows down an inclined plane and leaves the slide lip at a suitably formed edge, where it forms a freely falling liquid sheet, the curtain. The flow in this sheet forming zone is governed by gravity, inertia, capillarity and viscosity. At the contact line at the lip, a sudden acceleration of the fluid takes place due to the transition from no-slip boundary condition on the slide to a stress free surface of the sheet. This sudden change of the boundary conditions causes a pressure singularity in the vicinity of the edge, which causes a deflection of the sheet. This effect is well known as teapot effect in literature [1]. The magnitude of the deflection of the sheet depends on the flow rate $\dot{q}$, characterized by a Reynolds number $\mathrm{Re} = \dot{q}/\nu$ (with a characteristic kinematic viscosity ν), the geometry of the die lip and the material properties, especially the wetting behaviour. In Kistler and Schweizer [1] results of the deflection of the curtain in dependence on Reynolds number and contact line position are presented. In a recent study, the influence of the curvature of the edge of the lip on the deflection of a plane liquid jet of a paper coating device has been investigated at moderate Reynolds numbers [2,3]. The edge curvature is essentially determined by the available manufacturing accuracy and by considerations of robustness of the coating device, e.g. towards abrasive coating fluids [2].

Many coating fluids used in technical applications have a non-Newtonian behaviour. A commonly used model to describe the shear rate dependence of the viscosity is the Carreau model

$$\mu(\dot{\gamma}) = \mu_\infty + (\mu_0 - \mu_\infty)(1 + (\dot{\gamma}/\dot{\gamma}_0)^2)^{(n-1)/2}$$

which is suitable for modelling e.g. coating colors for paper coating or adhesives.

The paper to be presented describes a study of the influence of coating fluid rheology, lip geometry and flow rate on the deflection of the falling liquid curtain in the sheet forming zone. It was motivated by an application in an industrial coating plant. For illustration numerical results of flow simulations of the falling curtain in the sheet forming zone are shown here in Fig. 1 for four different adhesives (A-D) with different rheological properties. The coating fluid flows down a short vertical wall and leaves, for the configuration shown here, the lip at a ideally sharp edge with a pinned contact line. In the vicinity of the contact line, a localized region of low pressure develops, which causes the deflection of the sheet. Although the rheological properties of the four fluids differ only moderately from each other, cf. Fig. 2 (made dimensionless with common characteristic scales μ_c and $\dot{\gamma}_c$), yet a rather pronounced influence of the rheology on curtain deflection can be seen in Fig. 1. In a numerical parameter study this interplay of rheology with lip design and operation conditions (flow rate) will be investigated in detail, in order to find a configuration for both geometry and material properties that minimizes curtain deflection. Also, a comparison of the numerical results with experiments will be carried out.

Figure 1 Teapot effect for different coating fluid rheologies (Adhesive A-D): horizontal deflection of the curtain. Color contour: pressure field (red: atmospheric pressure, blue/green: low pressure region, Re = 5)

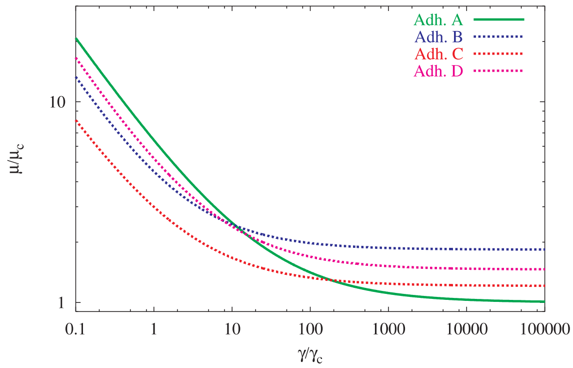

Figure 2 Rheology of the four adhesives A-D (dimensionless), modelled as Carreau fluids.

References

[1] S.F. Kistler and P.M. Schweizer: *Liquid Film Coating*, Chapman & Hall, 1997.

[2] M. Kustermann, F. Fischer, N. Alleborn and D. Gerlach: Parameters affecting coating color impact on the travelling sheet. *2006 TAPPI Coating & Graphic Arts Conference*, 24.-27. April 2006, Atlanta, USA.

[3] D. Gerlach, N. Alleborn, M. Kustermann and F. Fischer: Fluid dynamics of jet coating. In *13th International Coating Science and Technology Symposium - Final Program and Extended Abstracts*, ISCST - International Society of Coating Science and Technology, 10.-13. September 2006, Denver, USA, pp. 266-269.