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Fluid stability on a rotating roll

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Summary

Misting and other similar defects can often limit operation speed of some types of coaters such as forward roll costers, size presses and printing presses. Recent work has captured the breakup of septa at the roll exit that can break in certain ways to generate drops. However, the stability of the remaining septa were not followed. Images we have obtained show the ejection of drops even far from the nip exit.

A model is proposed here to study the stability of a filament remain on a rotating surface that is subject to centrifugal forces. A lubrication analysis that is symmetric around a high point is developed. The growth or decay of the disturbance is reported and compared to experiments.

Introduction

The literature on misting is reviewed by a recent publication that also reports some basic results of misting of a Newtonian liquid in forward roll coating (Owen *et al*. 2011). Misting was linked back to speed of the roll surfaces and viscosity: a dimensionless misting number was proposed to correlate the results. Images of the breakup of the septa at the nip exit explains how some misting occurs, but recent images in our laboratory show that even far from the nip, filaments can still be attached on end to a roll surface and thin due to centrifugal forces. Figure 1 shows an image for a magenta ink film. Upon careful inspection, it is clear that some of the filaments are shedding drops that fling well away from the nip exit.

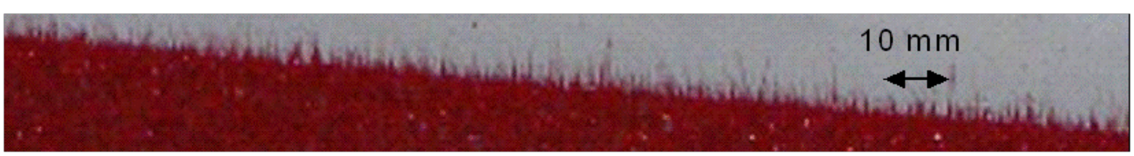

Figure 1. View of the roll surface 90o away from nip exit showing numerous ink filaments being extended and thinned due to centrifugal forces.

This flinging mechanism has been discussed before, but a careful look at the results compared to experiments are lacking in the literature. Here, we build on the model first described by Roper *et al*. (1997) and use the non-linear model to explore the stability of a filament on a roll surface.

The time scale for a filament to extend and shed a drop is compared to the time scale to rotate on the roll surface.

Theory

A Newtonian fluid with some initial disturbance is assumed to be axi-symmetric around the high point of the non-uniformity, as shown in Figure 2. The centrifugal forces that are generated in the fluid layer, should augment the pressure P and given in terms of roll radius R, fluid density ρ, and velocity U as

$$P = \frac{\rho U^2 h}{R} \tag{1}$$

where h is the local thickness of the film. The radial momentum equation and conservation of mass, in the lubrication limit are

$$\frac{\partial P}{\partial r} = \mu \frac{\partial^2 v_r}{\partial z^2} \tag{2}$$

$$\frac{\partial h}{\partial t} = -\frac{1}{r}\frac{\partial}{\partial r}\left(\int_0^h v_r\,dz\right)r \tag{3}$$

where μ is viscosity, v_r is the r component of velocity. Eq. (2) is integrated subject to no slip condition at z=0 and a no stress condition at z=h to generate a velocity field. The velocity field is integrated in Eq. (3).

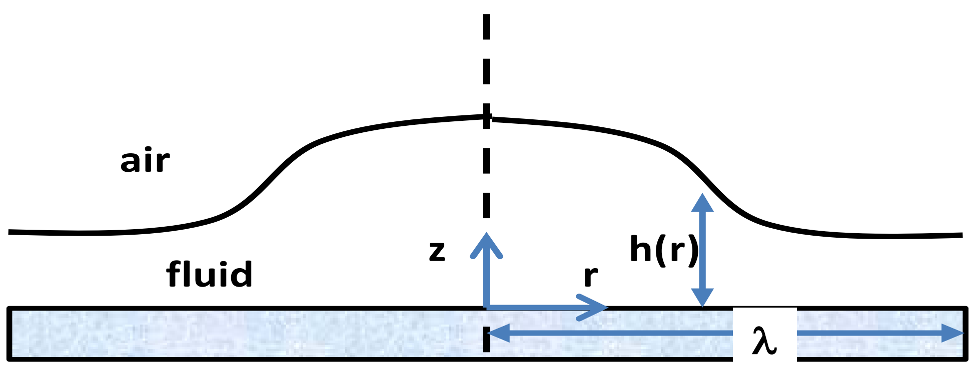

Figure 2. Schematic of the fluid layer on a roll surface.

Surface tension will act to pull the fluid to a flat layer. Pressure in the film should be uniform in the z direction. The Leplace equation links the curvature of the film to the local pressure due to surface tension approximately as

$$P = -\sigma \frac{\partial^2 h}{\partial r^2} \qquad (4)$$

where σ is the surface tension. Adding Eq. (1) and (4), taking a derivative with respect to r, and replacing the pressure gradient in the r direction, an evolution equation is obtained as

$$\frac{\partial h}{\partial t} = -\frac{1}{3\mu r}\frac{\partial}{\partial r}\left[r h^3 \left(\sigma \frac{\partial^3 h}{\partial r^3} + \frac{\rho U^2}{R}\frac{\partial h}{\partial r} \right) \right] \qquad (5)$$

This non-linear equation is solved with finite difference techniques starting from some initial shape of the fluid.

Figure 3 shows the evolution of a shape on a roll radius of 0.1 m, a roll surface speed of 10 m/s. a film thickness of 0.1 mm, a viscosity of 1 Pas, a surface tension of 30 mN/m and an initial disturbance of 0.05 mm. As expected, the high regions of the film grows, representing a filament attached on one end to the roll surface as in Fig. 1.

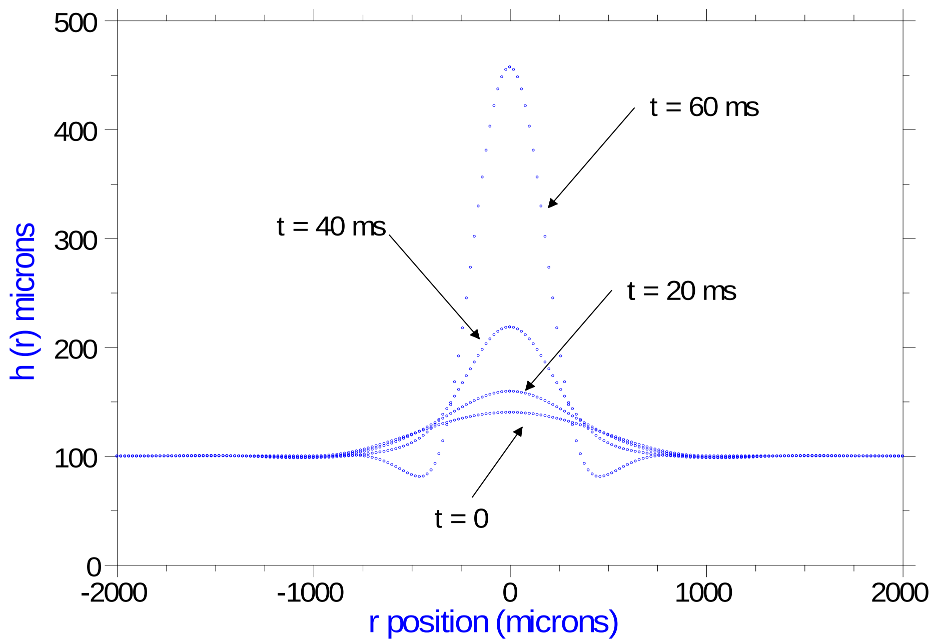

Figure 3. Shape of the fluid layer at various times for roll surface speed of 10 m/s, starting from a 0.05 mm disturbance.

Figure 4, showing just the right side of the fluid, shows the effect of an even smaller roll radius, that will generate stronger centrifugal forces. The shape of the film is even sharper. The surface tension forces also are strong as the fluid makes a sharp interface. Figure 5 shows a case with a smaller rotation rate or velocity: the film deforms still to a shape, but surface tension forces are able to hold that shape to prevent further fluid deformation. The model seems quite able to study a wide range of parameters.

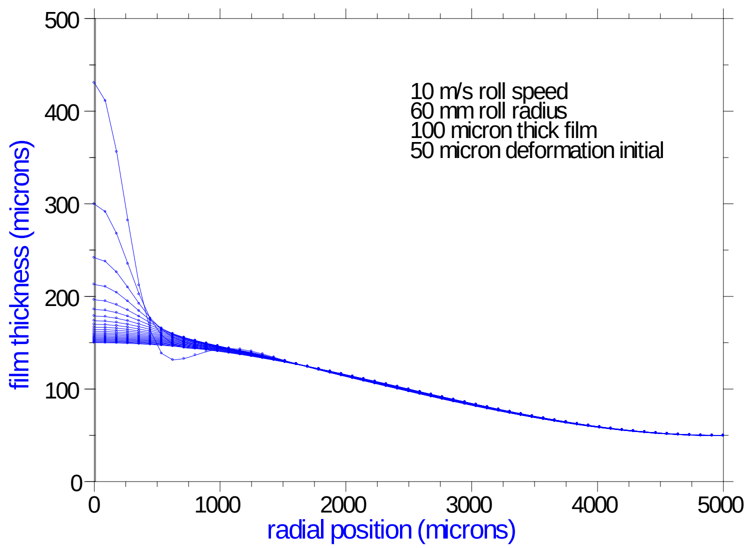

Figure 4. Similar to Fig. 3 but with a smaller radius of the roll.

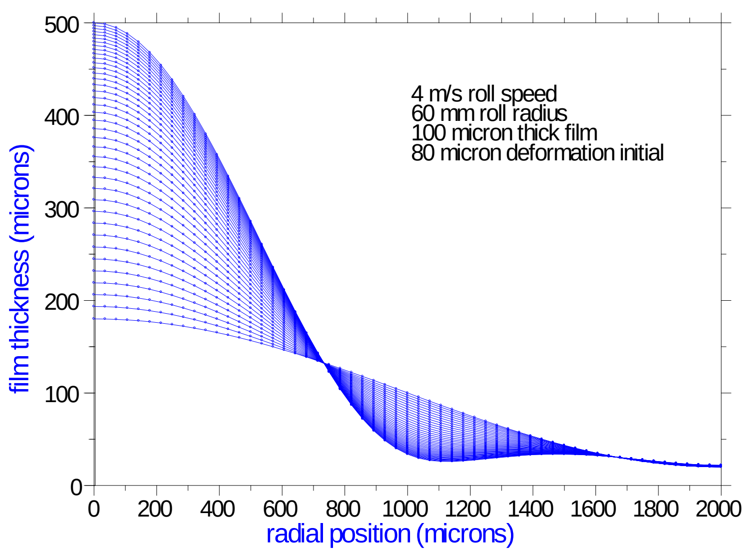

Figure 5. Similar to Fig. 3 but a slower roll speed. Shape deforms to a steady shape.

A key result is shown in Figure 6: the time for a disturbance to grow is a strong function of the initial fluid disturbance. A large disturbance can generate a rapid growth. A small disturbance takes a long time for the growth. The septa that form at the nip exit would be considered large disturbances.

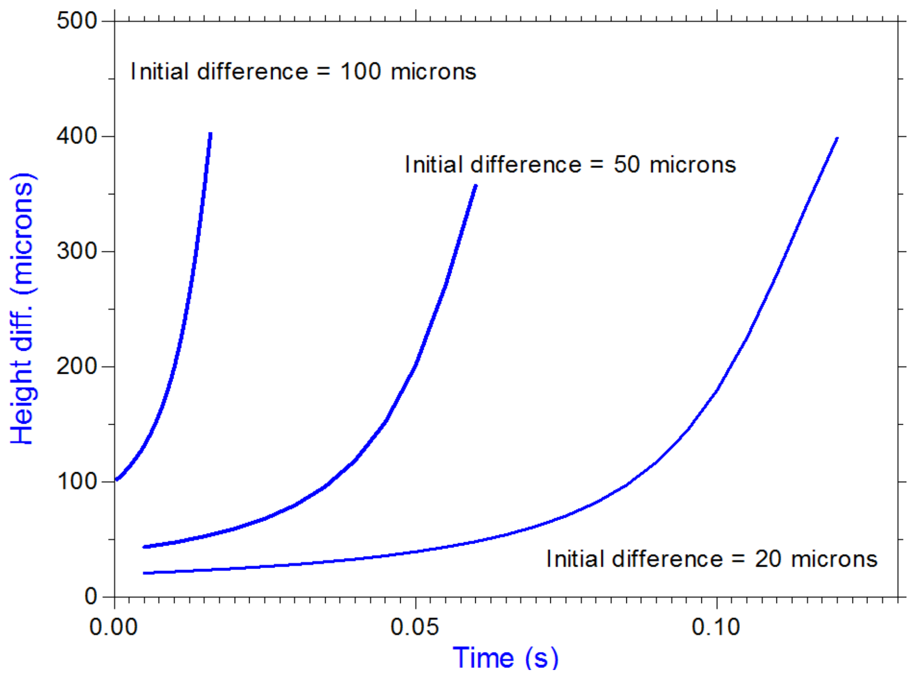

Figure 6. Disturbance growth for different initial disturbances. The time to grow from 20 mm case is longer than the time to travel around the roll.

Summary

A model is developed that predicts the slinging or fluid from a roll surface. The model agrees qualitatively with the experimental observations. A large initial disturbance is required to have time for the growth of the instability for conditions that resemble printing.

Acknowledgements

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References

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Roper, J.A., D.W. Bousfield, R. Urscheler, and P. Salminen, “Observation and proposed mechanisms of misting on high-speed metered size press coaters”, *Proceedings of the TAPPI Coating Conference*, pp. 1-14, TAPPI Press, Atlanta, GA, (1997).