OPERABILITY LIMITS OF CURTAIN COATING PROCESS

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Curtain coating is one the preferred methods for precision coating that has been used to manufacture single and, most notably, multilayer coatings and patch coatings on substrates or webs moving at relatively high speeds. Liquid falls as a sheet, or curtain, freely over a considerable height and under the action of gravity before it impinges onto the substrate being coated. Precision curtain coating was originally developed for multilayer photographic film but its use has expanded to many different applications such as optical films and specialty papers. Some advantages of this process include very high coating speeds, adaptability to a wide range of liquids and flexibility to apply thin liquid layer to irregular surfaces. In this process, the flow can be divided into several subregions to systematically analyze the flow dynamics of this process: film flow region on the inclined slide, curtain forming region around the slide lip where the liquid changes its direction, curtain flow region beyond the lip where the falling liquid experiences uniaxial extensional deformation by gravity force, impingement region where falling liquid impacts the moving substrate, and take-away region where liquid attains fully developed plug flow with the substrate speed.

In this work to study the operability limits of the process we focus on two main regions: the curtain flow region and the impingement region. The operability limits of the process are set by different flow instabilities in the coating bead, such as air entrainment, low speed heels and curtain pulling in the impingement region, and by curtain breakup in the curtain flow region. Edge guide are needed to maintain at specific width of the falling curtain.

Experimentally, one of the first noticeable contributions was brought on by Brown [1], who studied the shape and stability of a curtain falling over a moving surface (which mimics the coating processes). He suggested that a simple stability criterion could be built by comparing the momentum flux $\rho h U^2$ pushing downstream possible transient holes (ρ is liquid density, h is local curtain thickness, and U is local fluid velocity) with twice the surface tension γ, that tends to pull the hole upstream. This naturally introduces the Weber number $We=\rho h U^2/\gamma$ or $We=\rho q U/\gamma$ as a key parameter for curtain stability. Brown's conclusions were that the Weber number had to be larger than 2 to prevent any curtain break-up. In the impingement region, it is known that viscous drag by a moving substrate, the velocity of which exceeds a critical value, causes air to be entrained in the liquid. When the critical velocity is reached, the dynamic wetting line becomes unsteady, breaks into two or forms between the liquid and the substrate.

The goal of this research is to analyze these operability limits by theory and experiments. The focus is to determine the effect of operating parameters; edge guides design and polymer additives on the coating solution on the bead configuration and liquid curtain.

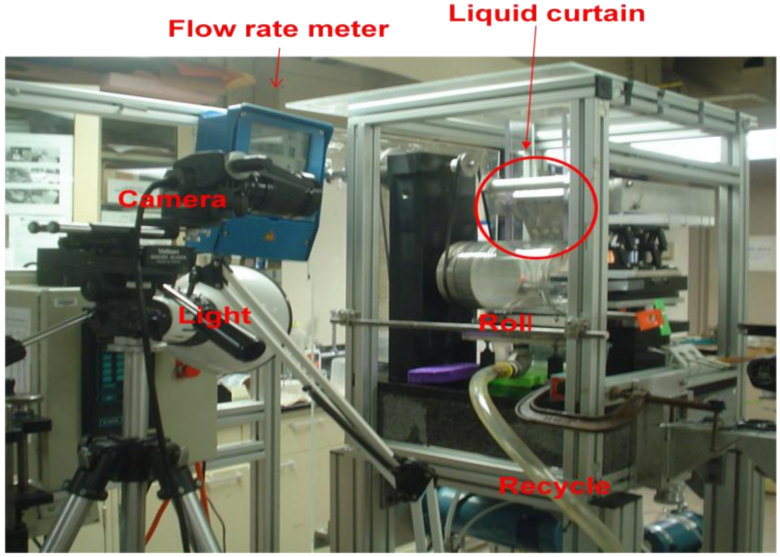

Fig.1: Photography showing the main features of the experimental curtain coater.

The experiments were conducted in the bench top setup shown in Fig. 1. The goal of the experiments was to study curtain break-up and the position of the dynamic contact line as a function of the operating parameters. The liquid used in the experiments was a glycerin-water solution. The viscosity was μ= 44 cP and the density ρ= 1180 Kg/m^3.

At each roll speed, the flow rate was slowly decreased until the curtain broke, as illustrated in Fig. 2(a). the break-up always occurred near the edge guides and at Weber numbers larger than the critical value of *We*=2 proposed by Brown. High speed imaging revealed that the break up was associated with small bubbles in the curtain, as illustrated in the Fig. 2(b).

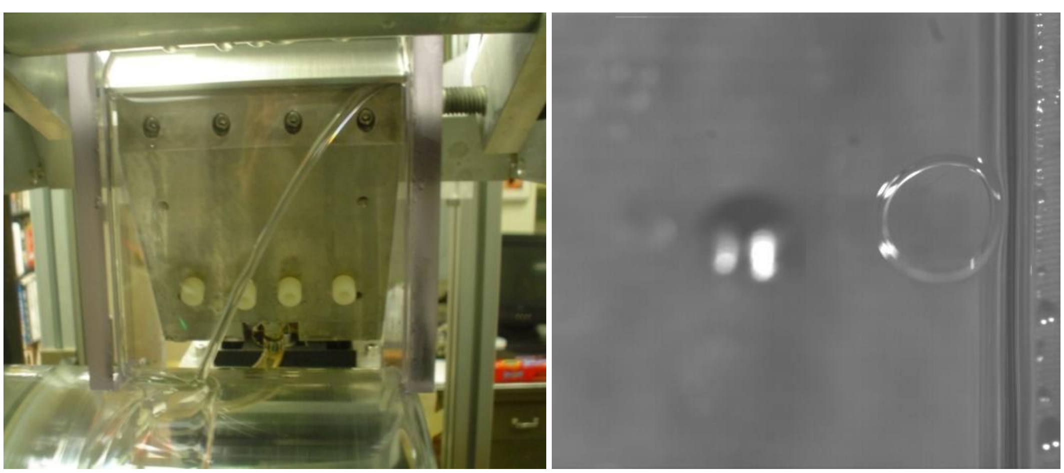

Fig.2: a) Curtain break-up b) Magnification view near the edge guide, break- up from bubbles. (High velocity camera)

The position of the dynamic contact line as a function of capillary $Ca = \mu V/\sigma$ and Reynolds number $Re = \rho\, q/\mu$ is shown in Fig. 3. The limits in the range of Reynolds number explored were the curtain breakup and the maximum flow rate of the pump. The results show the heel formation at low Capillary number.

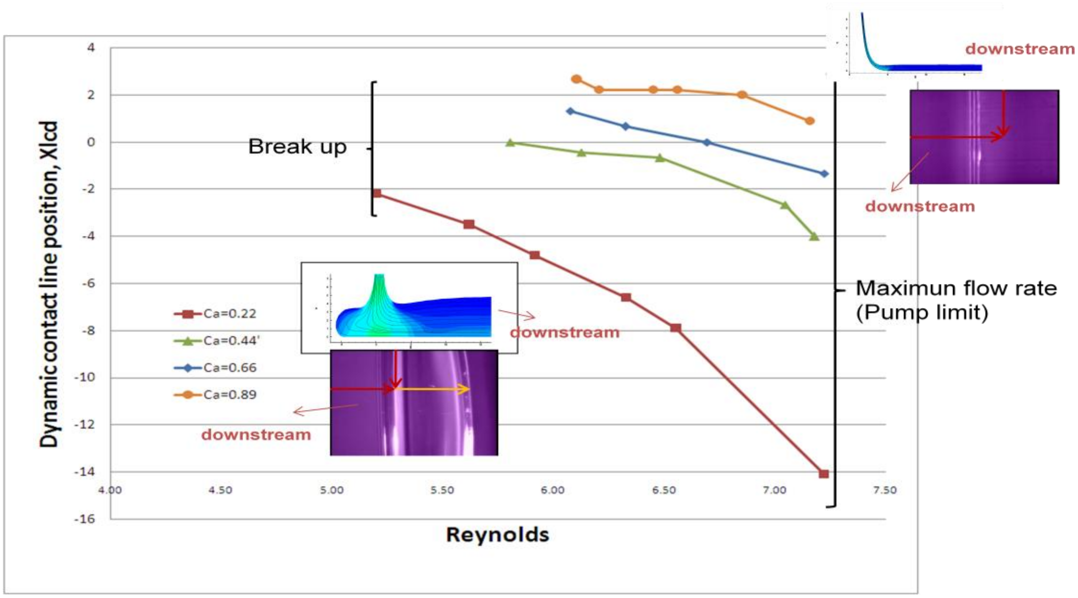

Fig.3 Dynamic contact line behavior

In the theoretical analysis, the flow was assumed in taken as: steady state, incompressible and two dimensional flow. The conservation mass and momentum equations with the boundary conditions were used to describe the flow. The equations were solved all together by Galerkin's method with finite element basis functions and non-linear system solved by Newton's method.

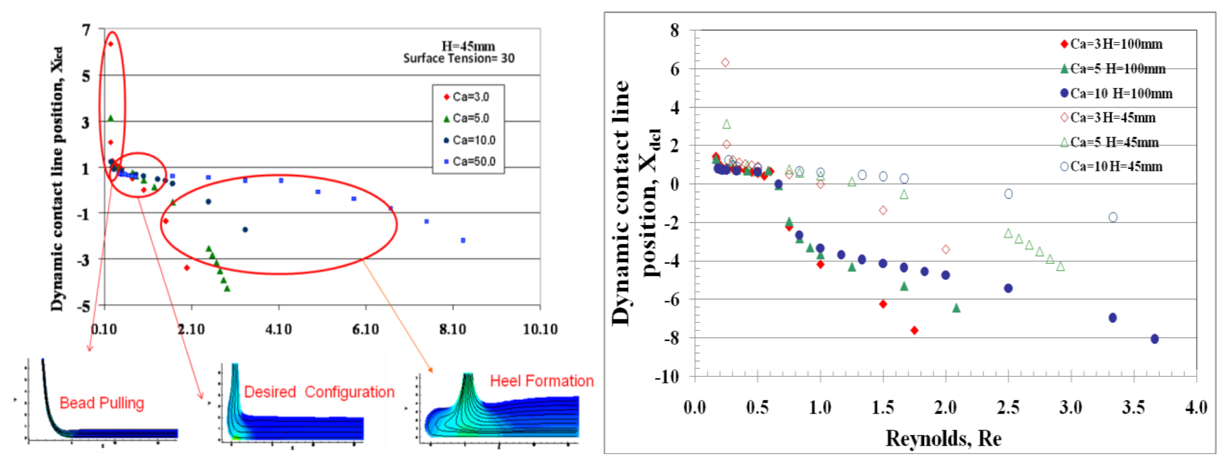

Fig 4. a) Dynamic contact line position for different capillary numbers at curtain height equal to 45mm. b) Influence of the height in the Dynamic contact line behavior.

Initial theoretical results, Fig. 4a, show the bead configuration; including heel formation and curtain pulling as a function of web speed (Capillary number) and flow rate (Reynolds) at specific curtain height, H=45mm. In Fig. 4b, results from a curtain height equal to 100 mm are compared with results from a curtain height equal to 45mm. It is known that long curtain involves higher velocity at the end of the curtain and affecting the flow rate at which bead pulling occurs Conditions of heel formation and bead pulling may be mapped as a function of Reynolds number and Capillary number as is showing in the Fig.5.

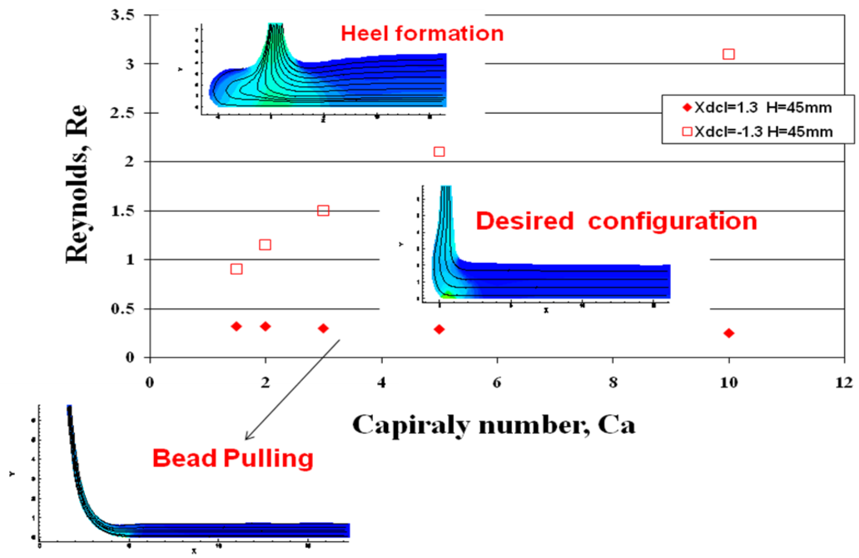

Fig. 5 Coating window as a function of the Reynolds number and Capillary number

References

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