Coatability of viscoelastic liquid curtain

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Introduction

Multilayer curtain coating has been used for more than 50 years in photographic industry for large volume production. One of the important operability limits of the process is the onset of air entrainment. Recent presentations at the 8th ECS in Karlsruhe [1] on the stability of viscoelastic liquid curtains concluded on strongly reduced application limits of curtain coating by stabilized liquid curtains trough the increase of viscoelastic behavior of the curtain liquid. While the stability of the curtain can be improved, the coatability of liquids with high apparent extensional viscosity is questionable. Almost no experimental data is available today in literature, dealing with the influence of extensional viscosity changes and their impact on coatability for multilayer curtain coating technology. The presented experimental data is thought to initiate theoretical reflections on the impact of viscoelasticity (herein represented by apparent extensional viscosity measurements) of the coated solution to the coatability limits of curtain coating.

Fluid characterization

In a first attempt different fluids have been analyzed in terms of shear and apparent extensional viscosity. Shear rates in the boundary layer at high speeds are in the order of 50'000 –200'000 $^1/_s$ [2]. Most practical and industrially used coating solutions are non-Newtonian under such circumstances. Therefore it was the goal to find a set of coating solutions, which have the same high shear viscosity values but strongly different apparent extensional viscosity. To do so a commercially available Polyvinylalcohol (trade name Mowiol 2288) has been chosen. To make the variation in elasticity a commercially available rheology modifier (trade name Tafigel AP30) has been used. The rheology modifier has been added in small quantities and the PVA concentration has been adapted in order to obtain the same high shear viscosity values. Out of the analyzed set of solutions, one with low, middle, and high level of apparent extensional viscosity has been selected for the curtain coating experiments. The shear viscosity and extensional viscosity data will be presented.

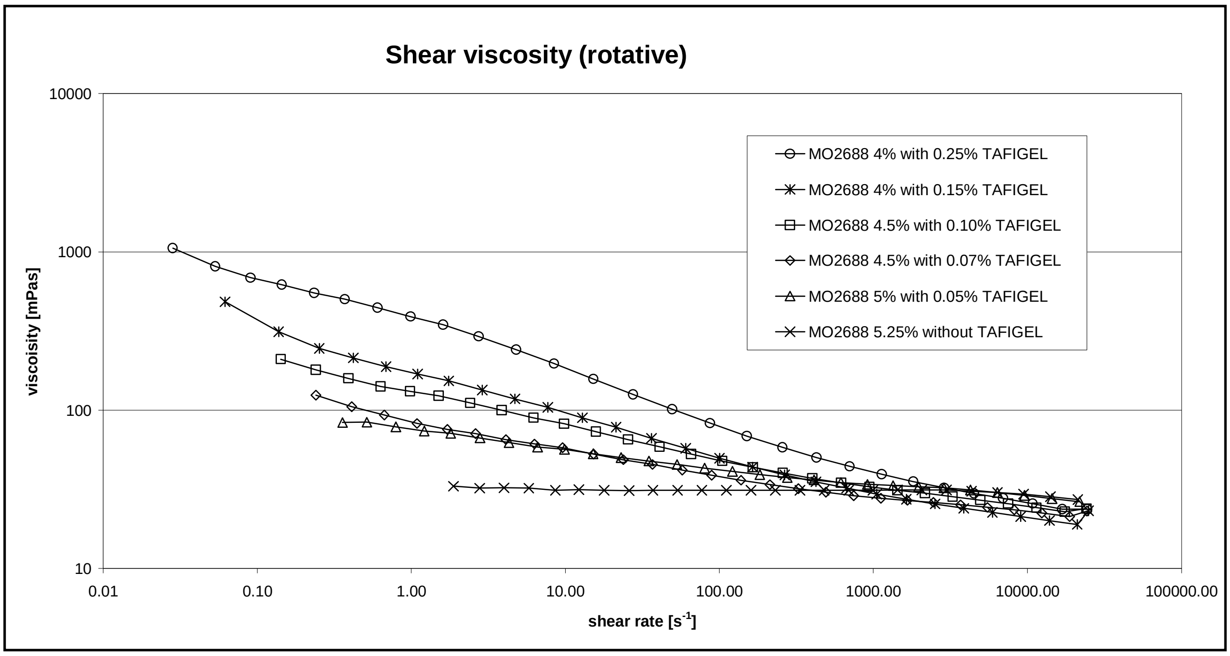

Figure 1: shear viscosity of 6 candidates of coating solutions measured at 25°C
on a Bohlin CVO-50 Research Rheometer

Experiments

In a first step we determined the stability of the curtain by measuring the minimum flow rates at which a break up occurred. In order to eliminate edge effects, the edge guides were tilted towards the curtain center (see figure 2). This assured the break up in the center of the curtain.

Figure 2: curtain break up at flow rate minimum

The coating window was then experimentally evaluated by coating 3 of the 6 solutions shown in figure 1 on resin coated base (PE-coated paper base) using multilayer curtain coating technology. The coating speed S [m/min] and the volumetric flow rate Q [cm^2/s] were varied up to the point where the coating fails due to air entrainment or heel recirculation or both. The coating was performed on a pilot coater (loop-coater) at Ilford Imaging Switzerland GmbH plant in Marly, where the coating speed can be varied in the range of 10 and 500 m/min. The trials have been performed with a curtain height of 75 mm and an impact angle alpha of 5.5 °.

Results

Curtain stability data shows, that it can be improved strongly by increasing the extensional viscosity of the fluid as found by Becerra et al [1], (see figure3). But even if the critical flow rates for curtain stability can be strongly reduced by viscoelastic liquids, it's not pushing the operative limit of about 1 cm^2/s down to significantly lower flow rates. Worse still, too high extensional viscosities can strongly reduce the effect of edge guides and therefore induce curtain break up at edges at higher flow rates than Q = 1 cm^2/s.

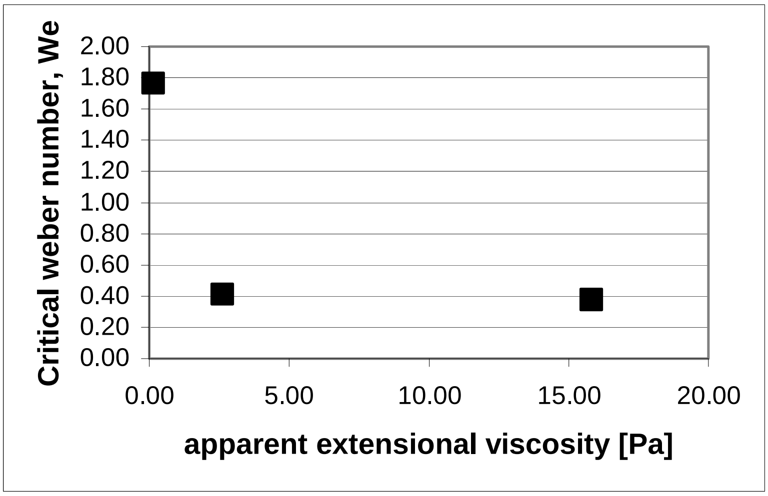

Figure 3: Critical Weber number as function of apparent extensional viscosity for curtain stability

Experimental curtain coating trial data will be presented, showing that coating liquids with higher apparent extensional viscosity is beneficial to push the onset of air entrainment to higher line speeds at medium and high flow rates. The collected data fits quite well the model of Blake, Clark and Ruschak [2], especially for the optimum relative line position. It is well established [3], [4], [5], [6], that air entrainment speed varies inversely with viscosity especially with Newtonian fluids. In most of the publications air entrainment data usually correlates by inverse power laws. However the measured data presented here shows, that for fluids with increased extensional viscosity this is not the case. Our data shows, that the critical speed for air-entrainment is strongly increased with increasing extensional viscosity, even if the apparent low shear viscosity of the fluid is dramatically increasing (figures 4 and 5). Similar contradictions to the inverse power law were found also by Martson [7] and Cohu [6]. The later found that the critical coating velocity of air entrainment doesn't follow the inverse power law for viscosity as soon there is an elastic component in the fluid.
The presented unexpected data in this study is suggesting that there exists an additional mechanism, not included in the model's of curtain coating until now, which can not been described by shear viscosity data alone. Our observation during the curtain coating experiments indicates that the variation of the relative wetting line position at higher flow rates is strongly reduced by increasing the extensional elasticity of the coating fluid. This means that the onset of air entrainment at higher flow rates is pushed to higher speeds due to the stretching behavior of the film at the curtain impact point, which is delaying the formation of a heel at the wetting line at higher flow rates.

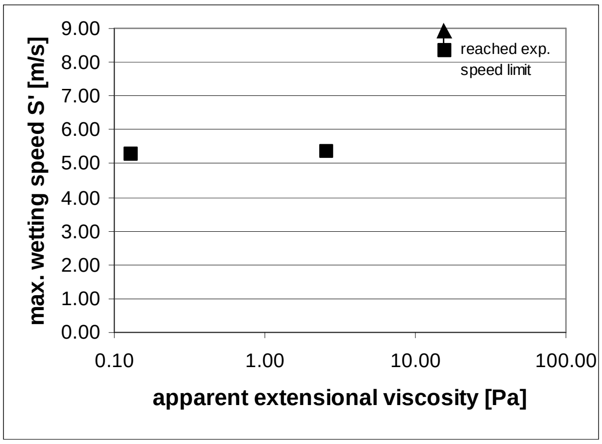

Figure 4: measured max. wetting speed as function of apparent extensional viscosity

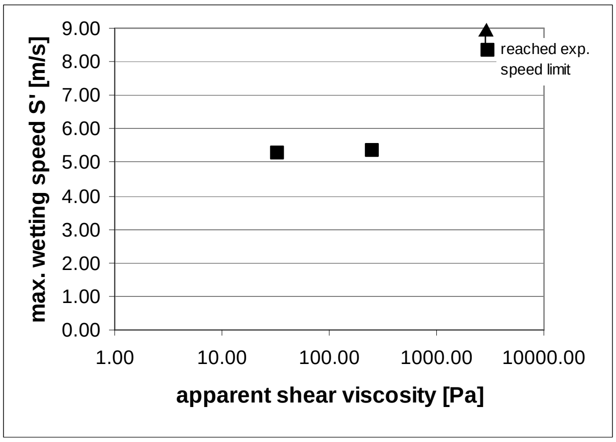

Figure 5: measured max. wetting speed as function of apparent low shear viscosity

Summary & Conclusions

An experimental investigation of the effect of fluid elasticity on the air entrainment velocity in curtain coating technology on smooth PE-coated substrates has been carried out. It was found that increased apparent extensional viscosity increases the critical velocities for dynamic wetting failure significantly, even in combination with strongly increased apparent low shear viscosities. The data suggests, that critical velocity correlates with a power law for apparent extensional viscosity. More experimental data is needed to establish a good correlation between apparent extensional viscosity, apparent shear viscosity and critical velocities for dynamic wetting failure. The following questions should be answered in the future - is the extensional elasticity of the coating solution a separate liquid parameter, that needs to be measured to predict coating speed limits, and does a model exist, that can explain both behaviors, following the power law, or the currently accepted inverse power law?

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