The misting phenomena in Roll Coating: Experiments and CFD simulations

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Introduction

Roll coating is the process by which a thin liquid film is formed on a continuous moving web using one or more rotating rolls. In forward roll coating, two rolls separated by a gap are used and these rotate in the same direction at the nip. Forward roll coating is the quintessential coating flow, attracting much research interest, particularly because it exhibits free surface ribbing instabilities at low speeds. When operated with deformable rollers at a negative gap, these instabilities can be masked (very small wave length and amplitude) and this makes deformable forward roll coating a simple and convenient method of producing very thin films (~10 microns) at reasonably economical speed (~2-3m/s). However, when the process is operated at higher speed (~5m/s), another form of instability appears, misting, which is the ejection of fine droplets formed during film splitting at exit of the nip flow. Misting is a serious limit to high speed coating as it affects the quality of coating coverage as well as creating environmental contamination.

The mechanism leading to mist formation in roll coating application process has been studied previously [1-5] and it is established that the development of high fluid pressure in the nip followed by low pressure at the nip exit [6, 7] is the main reason. Other instabilities also occurs as a result of the large tensile stresses forming: ribbing [5,6], filament formation [1,3] and cavitation when the pressure falls below vapour pressure [1-3,5,6].

Control or elimination of misting requires understanding the effect of flow geometryand dynamics which can be observed experimentally or predicted theoretically using CFD modelling. The rapid time frame involved in misting means that surface tension forces are less important, while rotational speeds are significantly important. Interestingly, a review of the literature did not reveal a clear correlation between misting and rheology, which is a-priori a critical parameter. In a recent review [8], fluid elasticity was found to be important, while another study [9] concluded that there is no correlation between misting and steady state shear viscosity or storage modulus .

Experimental Method

As expected, the experimental method consisted of a magnified visualisation of the nip. The camera used was a Vision Research Phantom 7.3 along with an infinity K2 microscope lens with a CF3 objective, giving a field of view about 1.5mm across, around 100mm working distance. The camera sensor resolution was 800x600 pixels maximum or ~2µm per pixel. The frame rate on the videos varied from 7000/s to 30,000/s. Microscope lenses usually have a very shallow depth of field, and to view the meniscus in the nip

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of the rollers, the lens needed to be at a shallow angle to the rollers. This setting allowed the meniscus to be in focus both in the nip and as it emerges from the nip. A very shallow angle can be created by looking through from the ends of the rollers, but this did not work: the end meniscus on the rollers is larger than the others obscuring the view and covers the lens in coating.

It was more successful getting the lens in line with the roller nip, at the shallowest angle possible, with the lens as close as possible to the top of rollers, as shown in Fig. 1. This requires a lens with long working distance, and very precise positioning of the camera. In order to achieve this, a tripod with a geared column was used to adjust the column in the z direction, a geared tripod head to do the three axes of tilt, yaw and roll, and geared micropositioning plates to do the x and y directions. The tripod fittings were required to be strong as well as precise, the camera along with microscope lens was 0.75m long and weighted 7kg. A high intensity machine-vision fibre light was used with precise positioning in line above the nip so that the light was cast straight down into the nip.

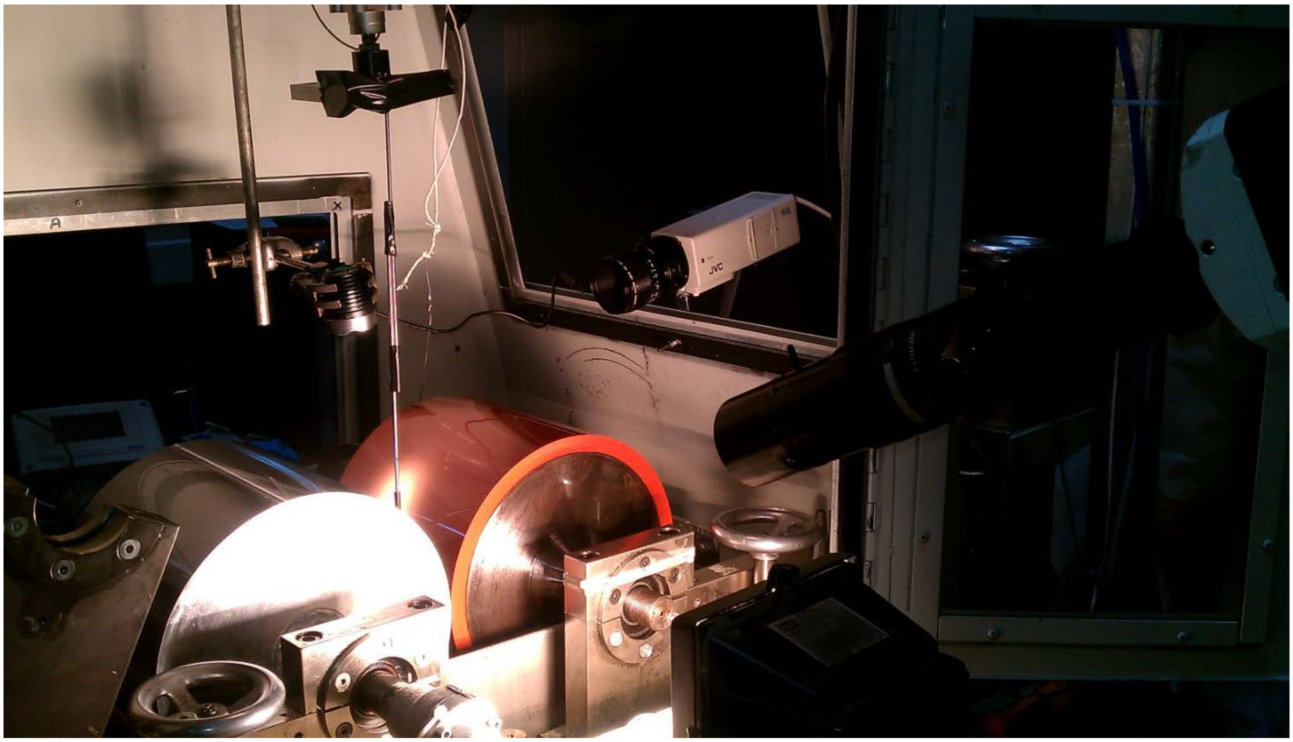

Fig. 1: Experimental set up for the study of misting

CFD Simulation Approach

The numerical simulations were performed with the open source CFD code OpenFOAM [11, 12], which is based on the finite-volume method (FVM). The interFoam solver was used for the solution of this two phase air-fluid flow problem and the volume-of-fluid (VOF) method [10] employed as the interface capturing scheme The approach was thus to solve both phases and as result predict the air entrainment speed and onset of misting.

Some Initial Results

Figures 2 and 3 give initial experimental and theoretical results. The visualisations revealed that as the roll speed increases, the ribbing lines formed before, start to extend further in longitudinal direction until, depending on the strength of the fluid molecular chains, they break forming the mist droplets. Thus, the extensional viscosity was found to play a significant role in optimising this unwanted phenomena and the onset of misting was found to be inversely related to the molecular weight of the systems as shown Fig. 2.

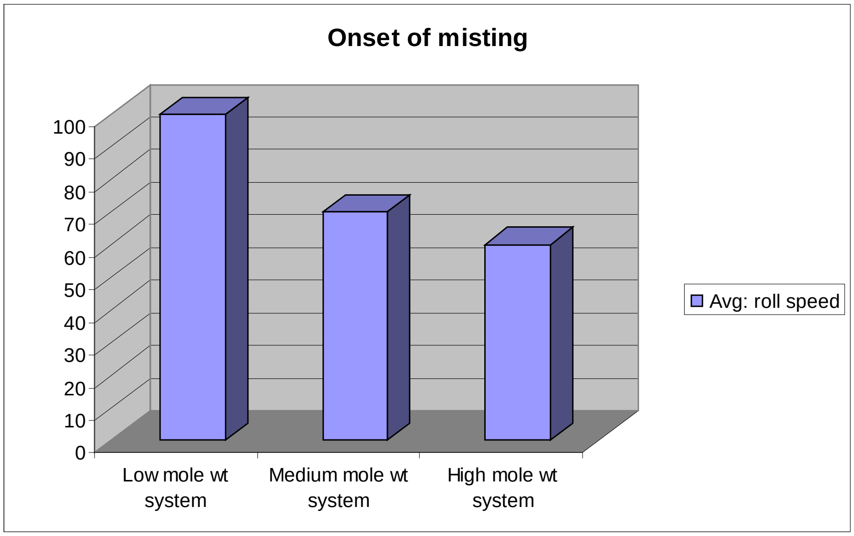

Fig. 2: Onset of misting with molecular weight of coating

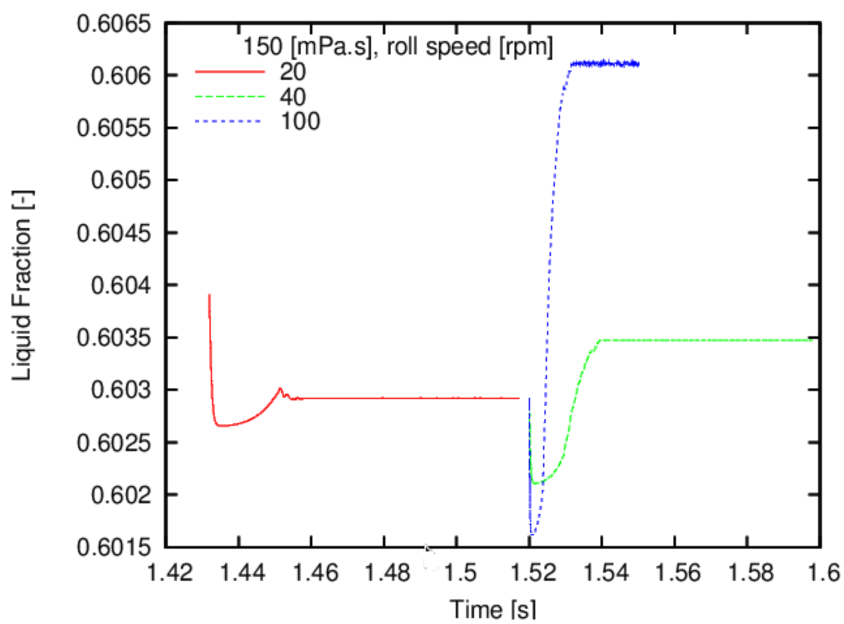

Fig. 3: Onset of misting with molecular weight of coating

Initially two series of CFD simulations were run, in order to investigate the effect on the meniscus position. In the first series, the viscosity was varied from 50 to 200 mPa.s and it was found that the meniscus moved closer to the gap, when the viscosity was increased. In the second series, the roll speed was increased, leading to capillary numbers from 1 to 10 and here it was found that the meniscus moved closer to the gap as the capillary number/ roll speed increased. Both these results were in agreement with the results found in previous work [13].

In the initial experimental analysis, the meniscus was moving up and down (which can then be seen as an instability) at around 100m/min. These results were validated through CFD analysis (Fig. 4), and the overall average alpha (volume fraction) was found to fluctuate at 100m/min and not at 20m/min or 40m/min roll speeds.

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