Analytical prediction of the behavior of multiple roll coaters with counter-rotating deformable rolls

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Abstract

In the presented work the previously validated analytical approach for the prediction of the film thickness in roll coating with deformable rolls and negative gaps is used to investigate the metering behavior of multiple roll coaters. The investigation covers especially 3 to 6 roll systems with different velocity ratio configurations. As a result it can be theoretically shown that the first roll pair and its configuration is mainly responsible for the metering in the system, while further roll pairs only contribute due to the splitting of the film. A comparison with data of rigid roll systems and positive gaps from literature shows a disagreement for the initial metering behavior and its influencing parameters but illustrates the fact of the same distribution behavior in both kinds of systems.

Introduction

Multiple roll coaters are widely spread for applying thin coating films on continuous substrates, e.g. papers, foils or coils. Key advantages are the comparatively simple technology and the possibility of coating thin films especially with deformable roll covers. Since roll coating is a self-metered process, the prediction of film thicknesses is of fundamental interest for the industrial process control. While deformable roll pairs with negative gaps are numerically and experimentally well investigated [1], for roll coating systems with deformable rolls only a few experimental investigations exist, e.g. [2]. The presented work should thus contribute to a better understanding of the behavior of roll coating systems and investigate the influence of the roll number.

Method of investigation

The investigation is performed using an own analytical approach for the prediction of the film thickness in roll coating with deformable rolls and negative gaps [3]. It has been validated previously for roll pairs [3] and extended using mass balances for five roll coaters [4]. These results have been successfully validated with experimental literature data from Krebs and Schweizer [2]. The used standard configuration uses the material and operational parameters given in Table 1.

Table 1: Material and operational parameters

Viscosity [Pas]	1.025
Roll radius [m]	0.1
Footprint [m]	0.01
Elastic modulus [Pa]	2000000
Rubber layer thickness [m]	0.02

For the comparison of roll systems with different roll numbers, series with geometric and arithmetic velocity distribution are used, according to the investigations of Benjamin for rigid roll systems [5].

Results

As a result of the investigations for 3 to 6 roll systems with 1 to 3 deformable rolls it could be shown that the first roll pair is mainly responsible for the metering in the system and predefines already the final coating weight. Since in all investigated configurations only the first gap meters the film and in all further gaps the inflow volume flow rate predefines the transported volume flow through the nip and no further metering occurs.

The metering behavior is influenced by the velocities of the first roll pair, the rubber thickness, its Young's modulus and the footprint between the rolls. In difference to rigid roll coating systems with positive gaps, the viscosity of the fluid is additionally influencing the final film thickness (see Figure 1).

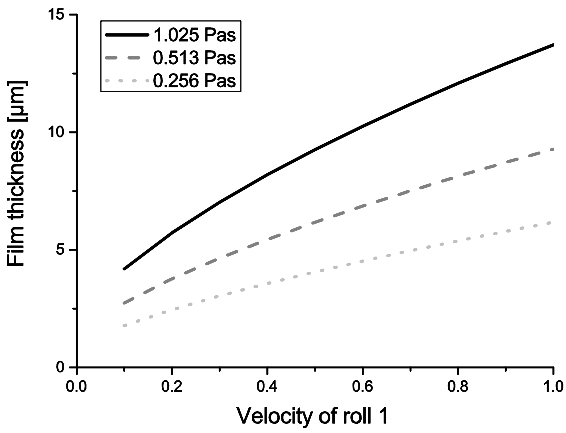

Figure 1: Dependency of the final film thickness on the velocity of the first roll for different viscosities for a 6-roll coater

An analysis of the behavior of the further, non-metering, roll pairs illustrates, that the distribution behavior is the same like the one described by Benjamin [5] in rigid roll coating systems (see Figure 2). The analysis includes common ranges of footprints and elastic moduli.

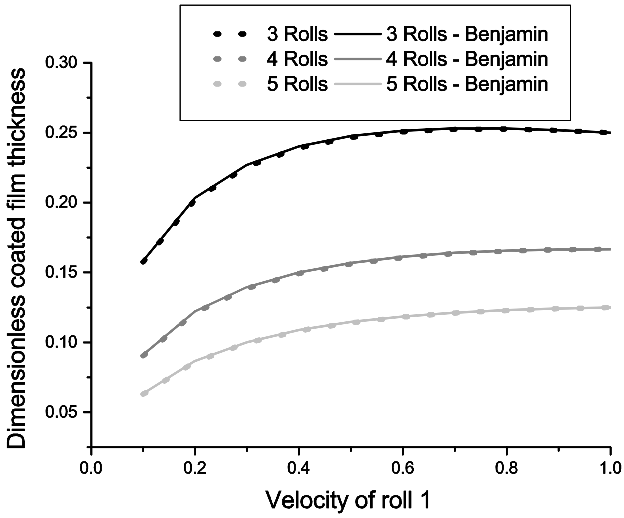

Figure 2: Distribution behavior of multiple roll systems

Consequently an equation for the final film thickness in multiple roll systems can be given, using own previous results for the description of deformable roll pairs and a mass balance equation similar to the one used by Benjamin [5] for the description of the distribution behavior in rigid roll coating systems.

The investigation of the influence of roll number shows that for high roll numbers above 5 to 8 the change in the final film thickness caused by adding another roll is comparably small. In these cases the benefit of higher substrate velocities or the possibly delayed onset of instabilities has to be checked critically before using systems with a higher roll number.

Finally the influence of a different arrangement or number of deformable rolls in the multiple roll systems has been analyzed, as exemplarily shown for a five roll coater in Figure 3. No difference concerning the final coating weight could be detected in the investigated configurations which includes 3 to 6 roll systems, with the restriction that all roll pairs of a system contain one deformable and one rigid roll.

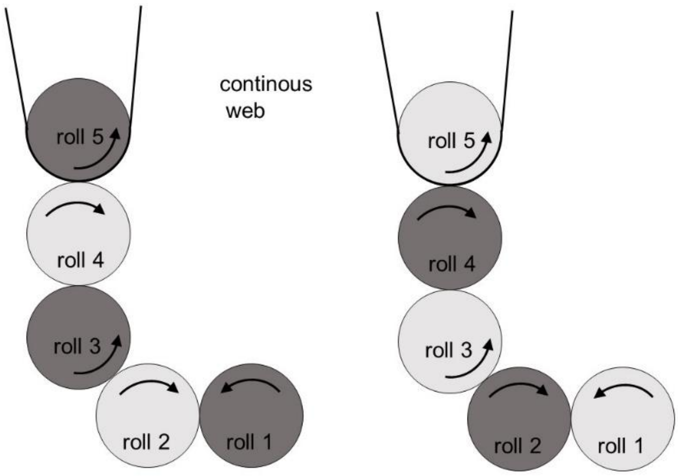

Figure 3: Different arrangement of deformable rolls

Conclusion

Summarizing the results it can be concluded, that the final coating thickness in multiple deformable roll coaters can be predicted with the own analytical method and a detailed analysis of the influencing factors is possible. It contributes to a better understanding of multiple roll systems and can help to set-up and operate multiple roll systems in industry.

References:

[1] S. J. Abbott, A review of deformable roll coating systems, Convert & e-Print 1 (2011) p. 89-93

[2] P. Schweizer, F. Krebs, 5-Walzen Beschichtungsverfahren, Coating 38 (2005) p. 214-217

[3] B. Willinger, A. Delgado, Analytical prediction of roll coating with counter-rotating deformable rolls, Journal of Coatings Technology and Research (2013)

[4] B. Willinger, A. Delgado, Analytical investigation of the behavior of five roll coating systems with deformable rolls, European Coating Symposium Proceedings, Mons (2013)

[5] D. F. Benjamin, T. J. Anderson, L. E. Scriven, Multiple roll systems: Steady-state operation, AIChE Journal 41 (1995) p. 1045-1060