

OPTIMIZATION OF OPERATING CONDITIONS IN MULTI-ZONE DRYERS FOR POLYMER COATINGS

P. Shrimal and M. Vinjamur

Department of Chemical Engineering
Indian Institute of Technology, Bombay, Powai, Mumbai 400 076.

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Many coated products are made by spreading a solution, prepared by dissolving a polymer in a solvent, on a substrate and then removing the solvent from the solution by blowing jets of hot air across it, from the bottom and the top, in multi-zone driers. Air flow, its temperature and its degree of saturation with the solvent constitute important operating conditions in every zone of an industrial drier. Air flow and its temperature can be manipulated easily in each zone to meet the goal of removing the solvent to specified levels without inducing any defects.

Drying of polymeric coatings in multi-zone driers, with each zone operated at different air flow and temperature, involves simultaneous mass and heat transport and shrinkage because of solvent evaporation. Mathematical modeling (Alsoy and Duda, 1998; Price and Cairncross, 2000) has been used extensively to study drying. Fick's law with a diffusion coefficient predicted by free volume theory (Vrentas and Duda, 1977 a, b) describes mass transport in the coating. A lumped model describes heat transport in the coating ignoring change in temperature across coating thickness and, shrinkage is obtained by solvent mass balance. We model poly (vinyl acetate) / toluene system in a two-zone drier.

Improper choice of operating conditions can create defects such as blisters, mottle, warping, crazing, and cracking. In this work, only blister formation during drying is considered. Blisters are created whenever the solvent partial pressure in the coating exceeds ambient pressure in the drier (Price and Cairncross, 2000). Intense operating conditions (higher air flow and/or higher air temperature) lead to faster solvent removal but are more likely to cause blisters in the coating. Mild conditions result in slower solvent removal and are less likely to induce blisters. In between, optimal conditions enable adequately fast solvent removal without generating blisters. The temperatures of the two zones and the total residence time were fixed and two heat transfer coefficients in the first zone (bottom and top), two in the second zone and the residence time in both the zones were optimized.

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Residual solvent at the end of second zone was the objective function, which was minimized with the constraint that the maximum bubble point pressure in the coating equals ambient pressure (atmospheric) during drying in both the zones. This also means that the coating temperature equals bubble point temperature in both the zones at some point during drying. Because solvent concentration is highest at the bottom of the coating, bubble temperature is lowest there and blisters are likely to be created there. If the coating temperature remains lower than the bubble temperature for the entire drying period, residual solvent is higher; if it exceeds, blisters are generated. The constraint ensures that the coating is dried at adequately intense air flow without generating blisters. Matlab built-in program “fmincon” was used for optimization calculations, which invokes the drying program to calculate residual solvent and bubble point pressure.

Figure 1 shows that as the residence time in the first zone is raised, for a total residence time of 80 s, the residual solvent falls to a minimum and then keeps rising. For short first zone residence times, the heat transfer coefficients in the second zone are lower and the coatings heats slowly there. Hence, the residual solvent is higher.

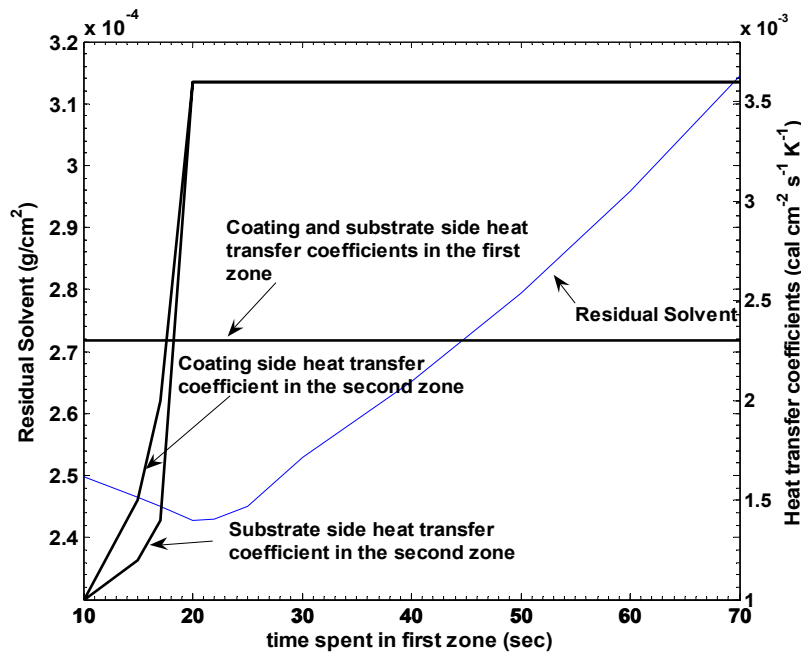


Figure 1: Sensitivity of the residual solvent and optimum heat transfer coefficients to the change in the first zone residence time. The total residence time is 80 seconds. The temperatures of the first and second zones are 393 K and 403 K, respectively. The coating is initially 148 microns thick and contains 30 % polymer by weight.

As the residence time in the first zone is raised, or, that in the second zone is lowered, the optimal heat transfer coefficients in the second zone rise and the residual solvent falls and reaches a minimum. For longer first zone

times, the residual solvent is also higher because the coating spends less time in the second zone, which is operated at higher temperature. Thus, the residence time in each zone needs to be optimized in order to minimize the residual solvent.

Optimization results show that the residual solvent keeps falling with rise in air temperatures in the first and second zones. Figure 2 shows the effect of polymer weight fraction on the optimal heat transfer coefficients in both the zones for first and second zone temperatures of 423 K and 433 K, respectively and for a total residence time of 80 s. As the polymer fraction rises, the diffusion coefficient of the solvent drops and, the drying rates become slower. Hence, the solvent concentration at the bottom of the coating drops slowly leading to a slower rise in bubble point temperature. This necessitates slower heating or use of lower heat transfer coefficients to avoid blisters. The optimal heat transfer coefficients on top and bottom of the coating were same in a zone. Those in the second zone are higher than in the first because bubble point temperature rises in the second zone and higher air flows are needed for the coating temperature to approach bubble point temperature.

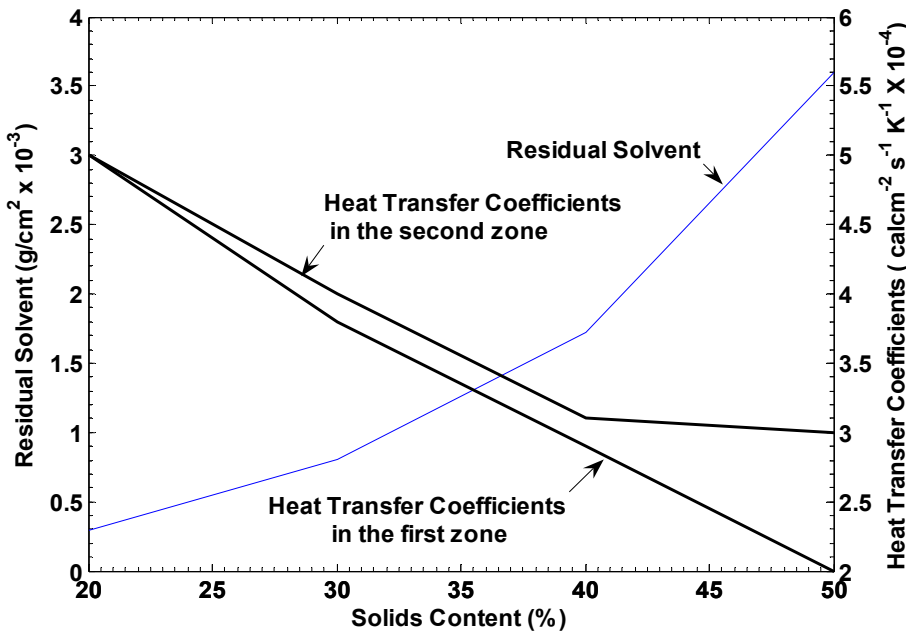


Figure 2: Dependence of optimal conditions and residual solvent on solids content. The total oven residence time is 80 seconds and the initial coating thickness is 148 microns. The air temperatures in the first and second zones are 423 K and 433 K, respectively.

Figure 3 shows the effect of polymer weight fraction on residence time in first and second zones for a total residence time of 80 s and for first and second zone temperatures of 423 K and 433 K, respectively. The coating

spends more time in the first zone as the polymer fraction increases because solvent concentration at the bottom of the coating falls slowly and therefore bubble point temperature rises slowly. Bubble point temperature rises in the second zone for longer residence time in the first zone and the coating can be dried at higher air flows in the second zone to minimize residual solvent. The trend in residence times is similar as the coating thickness is increased. Thicker coatings spend more time in the first zone so that bubble point temperature rises and the coating can be dried with higher air flows.

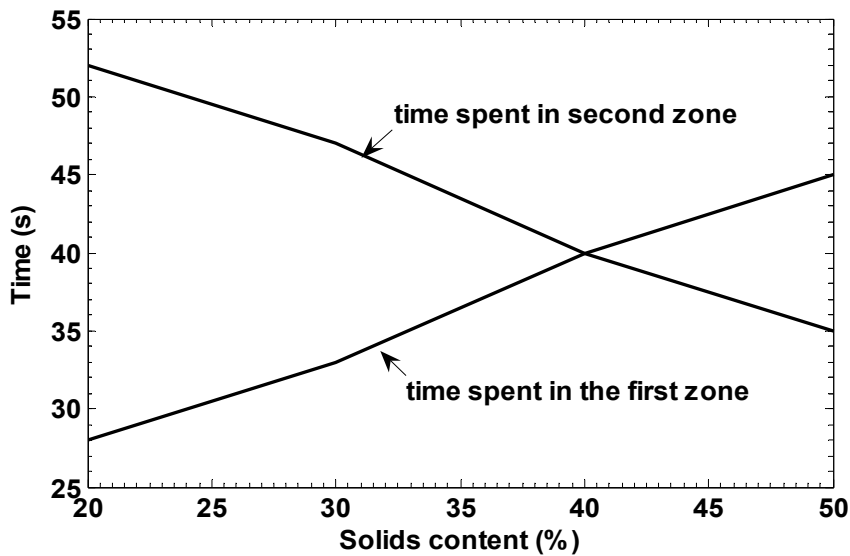


Figure 3: Change in the residence time in two zones with the change in initial solids content. The total oven residence time is 80 seconds and the air temperatures in the first and the second zones are 423 K and 433 K, respectively. The initial coating thickness is 148 microns.

References

- Alsoy, S. and Duda, J.L., 1998, "Drying of solvent coated polymer films", *Drying Technology* 16, 15-44.
- Price, P.E. and Cairncross, R.A., 2000, "Optimization of single-zone drying of polymer solution coatings using mathematical modeling," *J. Appl. Polym. Sci.* 78, 149-165.
- Vrentas, J. S. and Duda, J. L., 1977 a, "Diffusion in polymer-solvent systems I. Re-examination of free volume theory," *J. Polym. Sci.* 15, 403.
- Vrentas, J. S. and Duda, J.L., 1977 b, "Diffusion in polymer-solvent systems II. A predictive theory for the dependence of diffusion coefficients on temperature, concentration and molecular weight." *J. Polym. Sci.* 15, 417.