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# Profiled infra-red radiative heating in blow moulding and thermoforming

S. Monteix, F. Schmidt and Y. Lemaoult
Ecole des mines-Albi
Albi, Carmaux, France
81013 Albi CT Cedex 09

R.W. DiRaddo and D. Laroche
Industrial Materials Institute
National Research Council of Canada
Boucherville, Quebec, Canada, J4B-6Y4

A critical stage of both the injection-stretch blow moulding and thermoforming processes is the reheating stage, as the final part thickness distribution is strongly dependent on the preform or sheet temperature distribution prior to forming. Hotter preform or sheet zones will result in thinner part zones than colder preform or sheet zones. Also the resulting thickness distribution is highly coupled as the deformation history in one zone strongly affects the deformation histories in the adjacent zones.

The optimal forming temperature for both the thermoforming and injection-stretch blow moulding processes is between a lower and an upper bound temperature. The lower bound temperature is needed to ensure a low enough stiffness for formability, minimizing microcracks and sticking to the plug. The upper bound temperature is needed to ensure minimal sag, thin-outs during forming and colour changes. For example, the forming temperature range for a typical PP is between 143 and 166 °C, where the optimal is at 158 °C.

Optimization of the infrared oven is necessary to allow for minimization of energy costs. In most industrial infrared ovens, the ratio between electric power and absorbed energy in the plastic is approximately 15 %. An experimental methodology has been developed in order to characterise the heat source of the infrared emitter and the interaction between the lamps and the preform. The characterization of the oven performance is required to properly model the system. Directionnal aspects of the lamp are measured using a thermopile. The spectral properties of the infrared emitter have already been determined in a previous work [1]. A 880 LW AGEMA I.R. camera is used to evaluate the surface distribution of the transmitted heat flux by measuring the temperature distribution on the surface of the thermoplastic sheet. The experiments are conducted first for an opaque PP sheet and then for a semi-transparent PET media.

The transient temperature distributions for both thin gauge and thick gauge PP thermoformed sheets are predicted using a radiative heat transfer analysis. The material is assumed to be opaque, therefore the incident heat is totally absorbed by the surface. Both the effective radiative heat transfer coefficient (ranges from 20-25 W/m$^{2}$°C) and the effective bulk temperature (approximately 100 °C lower than the heater source temperature) are dependent on the IR heater source temperature, the system geometry, the heater efficiency and the amount of energy reflected at the polymer surface. The average effective radiative heat transfer coefficient, $H_{EFF}$, is estimated by

$$H_{EFF} = G + h \qquad (1)$$

whereas the effective bulk temperature, $T_{EFF}$ , is estimated by

$$T_{EFF} = (hT_A + GT_S)/H_{EFF} \qquad (2)$$

where G is the radiative heat transfer coefficient in a vacuum, derived from Boltzmann's law, h is the natural convection heat transfer coefficient from the polymer surface to the surrounding air, $T_A$ is the ambient air temperature surrounding the sheet and $T_S$ is the source heater temperature.

For the thin gauge sheet, a uniform effective radiative heat transfer coefficient and bulk temperature are assumed. The thin sheet has a uniform thickness of 0.15 cm and a surface area of 30 cm by 30 cm. The simulation results for the thin gauge sheet compare well to experimental results obtained on a pilot scale thermoforming machine, as shown in the Table. The minimum heating time for forming is obtained for heater settings of 250 and 270 °C.

| Source temperature °C | Experimental heating time (s) | Predicted heating time (s) |
|---|---|---|
| 250 | 105 | 120 |
| 270 | 87 | 83 |

For the thick gauge sheet, the dependence of the effective heat transfer coefficient and effective bulk temperature with sheet location is accounted for by incorporating location dependent view factors for two parallel square sheets. Heat transfer coefficients at the sheet extremities are upto 60 % the value obtained at the centre of the sheet. The thick sheet has a uniform thickness of 1.0 cm and a length and width of 100 cm. The heater temperature setting for the thick sheet is 600 °C. The simulation results for the thick gauge sheet are further complicated by gravity as the heavy sheet weight causes sag during the reheat stage. As the sheet heats up, the material's melt strength decreases and the zones at the extremities tend to thin out since they are pulled down by the material in the centre of the sheet. As the sheet thins out, it becomes hotter and sag becomes even more predominant. Simulation results will be further discussed the podium presentation.

## REFERENCES

[1] Le Maoult Y., F. Schmidt, El Hafi M., Lebaudy P., « Measurement and Calculation of Preform Infrared Heating », 4th International Workshop on Advanced Infrared Technology and Applications, Firenze, Sept. 15-16, 1997