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# ANALYSIS OF INFLUENT PARAMETERS DURING INFRARED RADIATIVE HEATING OF PET PREFORM

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The processing parameters during radiative heating of PET preform are:

- The number of infrared heaters  $N_h$ ,
- The temperature  $T_i$  of each infrared heater  $L_{i=1, N_h}$ ,
- The heating time  $t_h$ ,
- The cooling time  $t_c$ ,
- The coordinate vector  $\vec{x}_{i=1, N_h}$  of each infrared heater  $L_{i=1, N_h}$ ,
- The heat transfer coefficient  $h_c$  between cooling air and PET preform.

In previous papers [1,2], the spectral emissivity and directivity of different halogen lamps (Philips 300-700W electric nominal power made of a coiled tungsten filament, contained in a quartz tubular enclosure and a diffuse reflector made of a ceramic coating) have been reported. Recent measurements using a 0.6-25  $\mu\text{m}$  thermopile sensor on similar halogen lamps of 1000W (used in an industrial oven of injection-blow moulding machine) have been processed. The maximum temperature of the tungsten filament is 2400 K. As shown in fig. 1, these infrared heaters exhibit a slightly different behaviour from a lambertian source (diffuse radiation) due to the reflector. The average discrepancy is about 8 %. In order to take into account the participation of the diffuse reflector in the amount of the incident radiation, a coefficient of efficacy  $k_{\text{rf}}$  is introduced.

Fig. 2 shows the experimental set-up that has been developed in order to measure the surface temperature distribution (front face and back face), when a PET sheet is heating using previous infrared heaters. An 880 LW AGEMA infrared camera (8-12  $\mu\text{m}$  bandwidth) is used to measure the spatial and transient temperature distribution. The surface dimension of the PET sheet is 20cm  $\times$  20cm cm and the thickness is 1.5 mm.

A 3D control-volume model has been developed for computing radiative heat transfer during the infrared heating stage. The sheet-shape domain sketched in fig. 3 is discretised into cubic elements, called control-volumes [3]. The energy equation including radiative transfer integrated over each control volume  $V_e = \Delta x \Delta y \Delta z$  and over the time from  $t$  to  $t + \Delta t$  leads to:

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$$\int_{\Delta t} \int_{\Omega_e} \rho c_p \frac{\partial T}{\partial t} d\Omega dt = \int_{\Delta t} \int_{\Gamma_e} k (\nabla T \cdot \vec{n}) d\Gamma dt + \int_{\Delta t} \int_{\Gamma_e} \vec{\varphi}_r \cdot \vec{n} d\Gamma dt \quad (1)$$

Where  $\rho$  is the specific mass,  $c_p$  the heat capacity,  $k$  the heat conductivity.  $\Gamma_e$  is the surface of control-volume  $V_e$ . The assumption of “cold material” is convenient, as the PET bulk temperature ( $\cong 12^\circ\text{C}$ ) is very low in comparison to heaters temperature ( $1500\text{--}2000^\circ\text{C}$ ). Consequently, the net radiative transfer over each control yields:

$$\int_{\Gamma_e} \vec{\varphi}_r \cdot \vec{n} d\Gamma = k_{\text{eff}} F \frac{\Gamma_i}{\Gamma_e} \int_{\Delta\lambda} \varepsilon_\lambda(T_i) \pi L_\lambda^0(T_i) \left( \tau_\lambda^e - \tau_\lambda^e \right) d\lambda \quad (2)$$

Where  $e$  is the thickness of the PET film used to obtain an intrinsic transmission coefficient  $\tau_\lambda$ ,  $\varepsilon_\lambda$  is the spectral tungsten emissivity,  $L_\lambda^0$  is the black body intensity. The diffuse view factor  $F$  is computed using the contour integration method [4].

The integration of equation (1) over all the control-volumes leads to a set of linear algebraic equations, which is solved iteratively using the line by line Gauss-Seidel method in the y-direction to obtain a 3D-system computed by the TDMA algorithm.

An example of PET sheet heating has been processed. The dimensions of the sheet as well as the halogen lamps are sketched in fig.4. The thickness of the sheet is 3mm. The processing parameters for the infrared heaters are summarised in the table below. It is to be noted that in this simplified case, the distance between the lamps and the front face of the sheet is constant and equals to 50mm.

	$T_i$ (K)	$x_i$ (mm)	$y_i$ (mm)	$z_i$ (mm)
$L_{i=1}$	2200	40	-50	20
$L_{i=2}$	2000	40	-50	40
$L_{i=3}$	1700	40	-50	60
$L_{i=4}$	2000	40	-50	80
$L_{i=5}$	2200	40	-50	100

The heating time  $t_h$  is 35 s and the cooling time  $t_c$  is 25s. A constant heat transfer coefficient of  $10 \text{ W m}^{-2}\text{K}^{-1}$  is applied to the back and front faces of the sheet. The temperature distribution of the front face of the sheet is plotted as shown in fig. 5. In addition, fig. 6 shows the temperature distribution throughout the thickness versus time. The temperatures of the central lamps  $L_{i=2,3,4}$  have been decreased in order to improve the temperature distribution on the front face.

Simulations results will be further discussed during the podium presentation.

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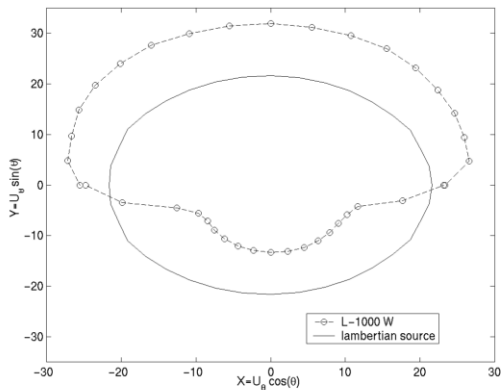


Figure 1: Halogen lamps (1000 W) directivity

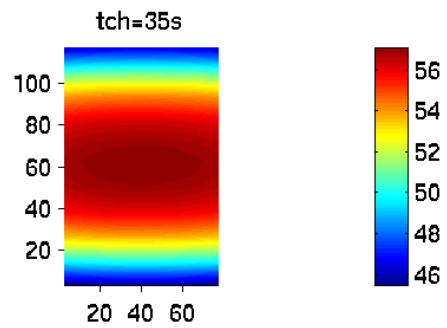


Fig. 5: Temperature distribution on the front face ( $t_h = 35s$ )

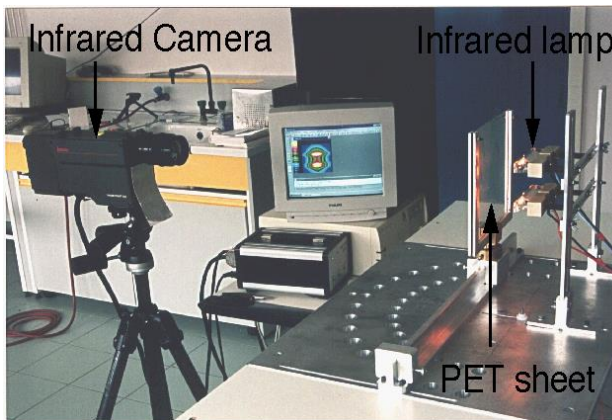


Figure 2: Experimental set-up for surface temperature distribution

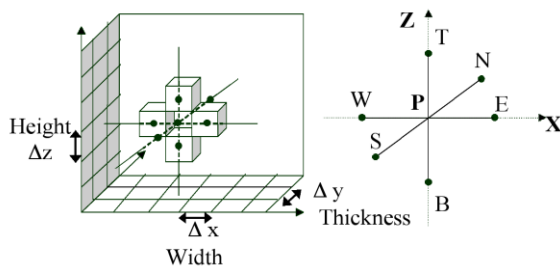


Figure 3: 3D control-volumes

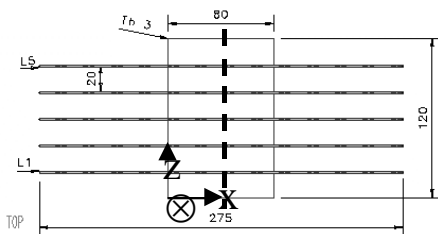


Fig.4: Dimensions of the sheet and the halogen lamps

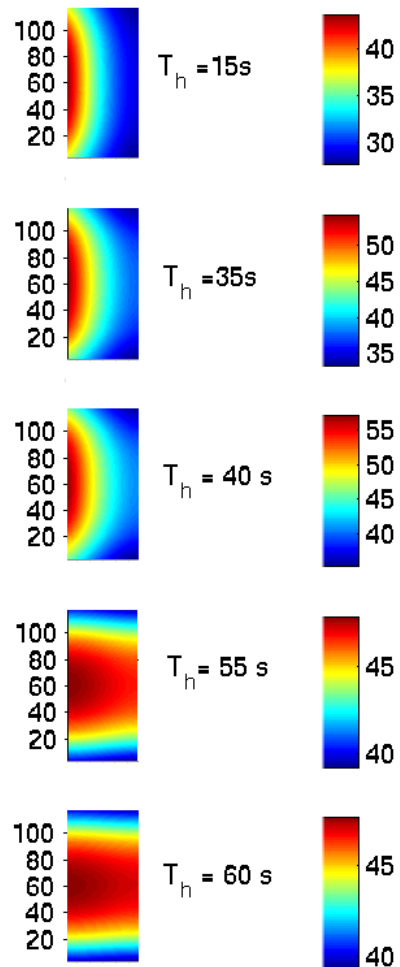


Fig. 6: Temperature distribution throughout the thickness versus time