32nd International Conference of the POLYMER PROCESSING SOCIETY-July 25-29, 2016, LYON





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Infrared Radiation applied to Blow Molding Process





Applications of radiative transfers in polymers processing



Industry	Activity	Elementary operation can be processed by IR		
Automotive	Body	Gluing, varnishing, painting, printing		
	Equipment	Surface treatment, gluing, forming, moulding,		
		embossing		
		Flocking, varnishing, painting, printing		
Thermoplastics,	Technical parts	Thermoforming, injection blow moulding,		
composites		gluing, welding, curing		
	Flooring	Varnishing, coating, polymerization, Foaming		
Textile	Finishing	Drying, dehydration		
		polymerization		
		thermo-fixing		
		coating		
	Technical textiles	Drying, heat treatment, gluing		
		polymerization		
		thermo-fixing		
		Forming, moulding, graining		
		coating		



Energy required producing bottled water [NIX 15]

Some industrial applications of infrared heating [ADE 02]

 Around half the total energy of a consumable bottle of water lending itself to manufacturing



Injection-stretch Blow Moulding (ISBM) for PET bottles forming











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Black body spectral intensity



Planck's law



Stefan-Boltzmann's law

$$I^{o}(T) = \int_{0}^{\infty} I^{o}_{\lambda}(T) d\lambda = \frac{\sigma_{SB}T^{4}}{\pi}$$

Wien's law







Radiative properties: Spectrometric measurements







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✓ Heat transfer equation including radiative source term

$$\rho c_{p} \frac{dT}{dt} = \vec{\nabla} \cdot (k \vec{\nabla} T) - \vec{\nabla} \cdot \vec{q}_{r}$$

Radiative source term

$$\vec{q}_{r} = \int_{0}^{\infty} \int_{S^{2}} \vec{\Omega} I_{\lambda}(\vec{s}, \vec{\Omega}) d\Omega d\lambda$$
Radiative flux Spectral intensity

✓ Radiative transfer equation

$$I_{\lambda}(s,\vec{\Omega}) = I_{\lambda}(s_{o},\vec{\Omega}) \cdot e^{-\kappa_{\lambda}(s-s_{o})}$$

Beer-Lambert's law



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 $\varphi = 2\pi R_1$

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Based upon ray tracing method [Cosson et al. 2011]

RAY-HEAT software basis

- Launching rays from the emitters (IR lamps)
- Computing paths of each ray and throughout the preform thickness
 - Snell-Descartes law at the interface air/PET
 - **Reflection conditions** >

Each ray looses radiative energy when crossing preform thickness



*R*₁ and *R*₂: **stochastic** variables in the

range [0,1] [Pharr-2004] :







ΡΡς

Transient radiative source term



Last step: sum of the rays contributing heating of preform

ightarrow Computation of radiative source term

$$\vec{\nabla} \cdot \vec{q}_{r}(s) = -\int_{0}^{\infty} \kappa_{\lambda} M_{\lambda}(0) \cdot e^{-\kappa_{\lambda} s} d\lambda$$

How to account for the preform rotation inside the IR oven?
 → Radiative source term defined as function versus time





In-lab blow molding machine







Temperature measurement



CS 325 FLIR infrared camera

[7.5–13.5 μm]

Halogen lamp: Philips 2 kW

P ₁ (%)	P ₂ (%)	P ₃ (%)	P ₄ (%)	P ₅ (%)
100	100	20	5	60

Heating time: 25 s

Cooling time: 10 s



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Numerical simulation



Radiative source term (RAYHEAT)

Temperature distribution (t = 25 s)





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Optimization problem



- Blowing of 0,5l bottle on SIDEL SBO1 machine (18g PET T74F9 preform)
- Production rate: 800 bottles/h





Optimized temperature & bottle thickness







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Future works



- ✓ Interaction of radiation and the microstructure of polymer (for example when adding submicronic mineral fillers or dyes in PET [BIL 12])
 - Rays may be refracted and radiation scattering ^(*) may occur
 - Rayleigh approximation or Mie theory [VAN 81] may be applied
- Measurement of absorption coefficient for semi-transparent polymers
 - In the case of specular reflection, we could take advantage of Kramers– Kronig [KIT 04] relation in order to assess to the absorption coefficient
- Characterization of heater lamps and more particularly halogen lamps still remains a big challenge



Infrared heating setup





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Acknowledgements





WILEY

The authors warmly thank all the PhD and postdoctoral students for their indispensable help, exciting scientific discussions and apologize to those they forgot to mention:

> Serge Monteix, Sylvia Andrieu, Cedric Champin, Maxime Bordival, Benoit Cosson, Sawsane Nakouzi, Johann Pancrace, Myriam Dauphin, Andre Chateau Akue Asseko and among others...

A special thought for our colleague Bernard Plantamura (Sidel Company) who left us prematurely in 2015



iSTE

Why using infrared heating for polymers?



Direct energy transfer between the source and the product to be treated

- ✓ High power density
- ✓ Radiation focusing

Control flexibility (low thermal inertia)

Adaptable and expandable



Spectral emissivity of pure tungsten





(S. Nakouzi, 2012; R. Siegel, J.R. Howell; 1992, S. Monteix, 2001)



Mesh/ Boundary conditions



✓ Lamps discretization (polar emission): 1.5 million rays per lamp

✓ Mesh of the preform: 20*10*30 = 6000 nodes





Non-scattering and cold medium assumptions





