

Modeling of IR Lamps with Coated Reflector Used in the Slurry Impregnation Process of Composite Tapes

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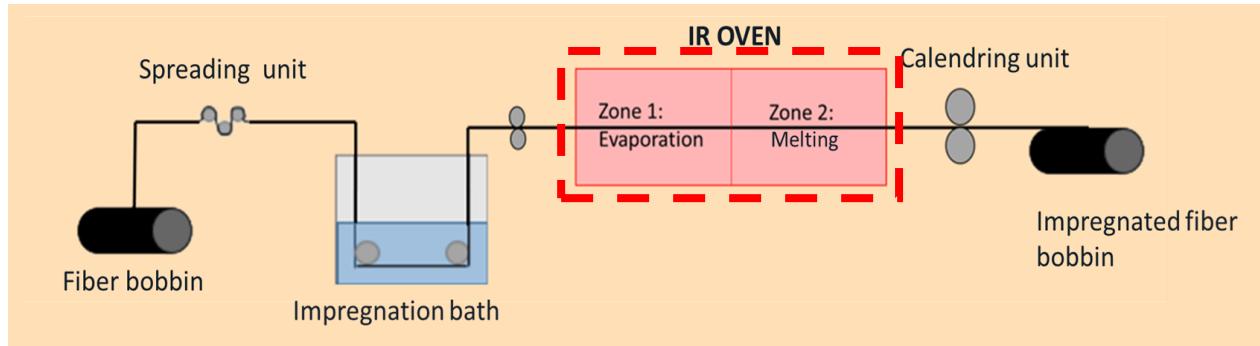
Industrial contexte

■ Thermoplastic impregnation line (IRT SE)

- Pre-industrial pilot
- Carbon thermoplastic (PAEK) prepreg (UD, Fabric...)
 - Prepreg width up to 300mm
 - Line speed up to 10 m/min
- Multi impregnation technology (Slurry, dry powder...)

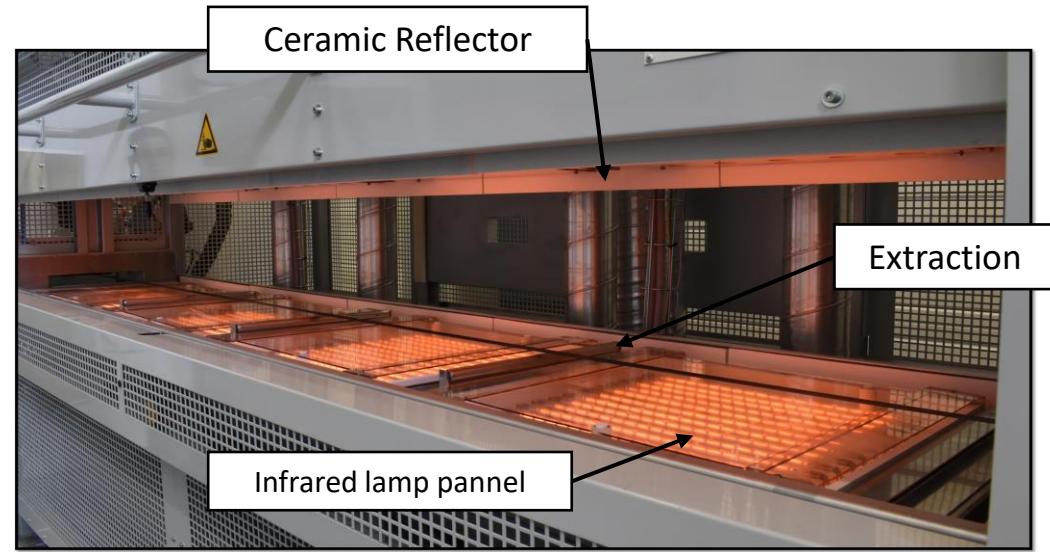
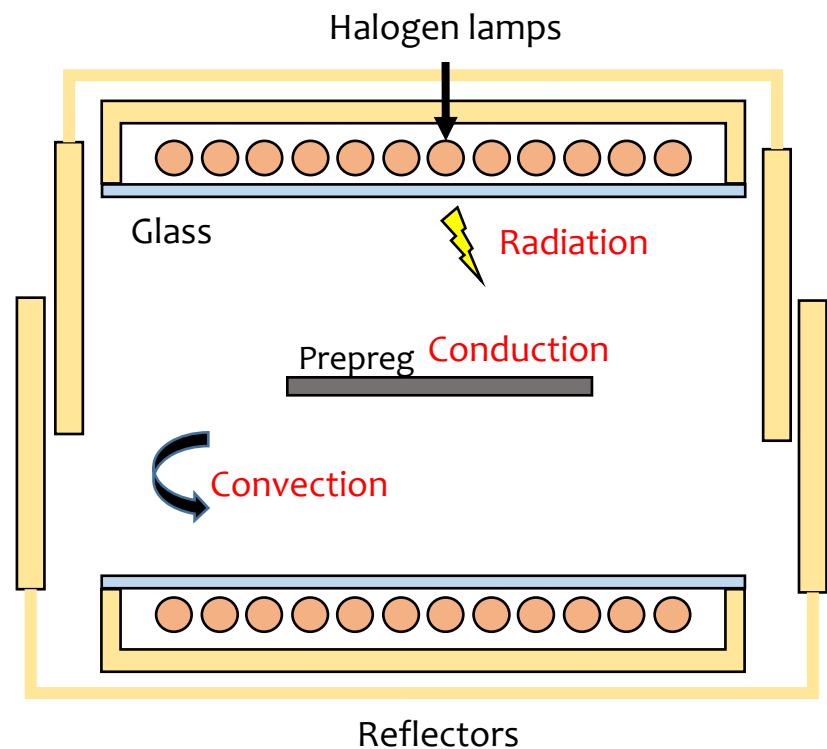
■ Project : METEOR

- Competitive thermoplastic prepreg

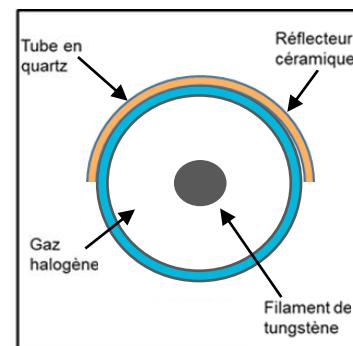


Scientific contexte

Modelling of the fusion/impregnation step in the fabrication process of thermoplastic preangs



Infrared oven – Thermoplastic impregnation line (IRT SE)



1st step → Modelling of Infrared oven

- Complex thermal environment
 - 3 modes of heat exchange
 - IR lamps with integrated reflector

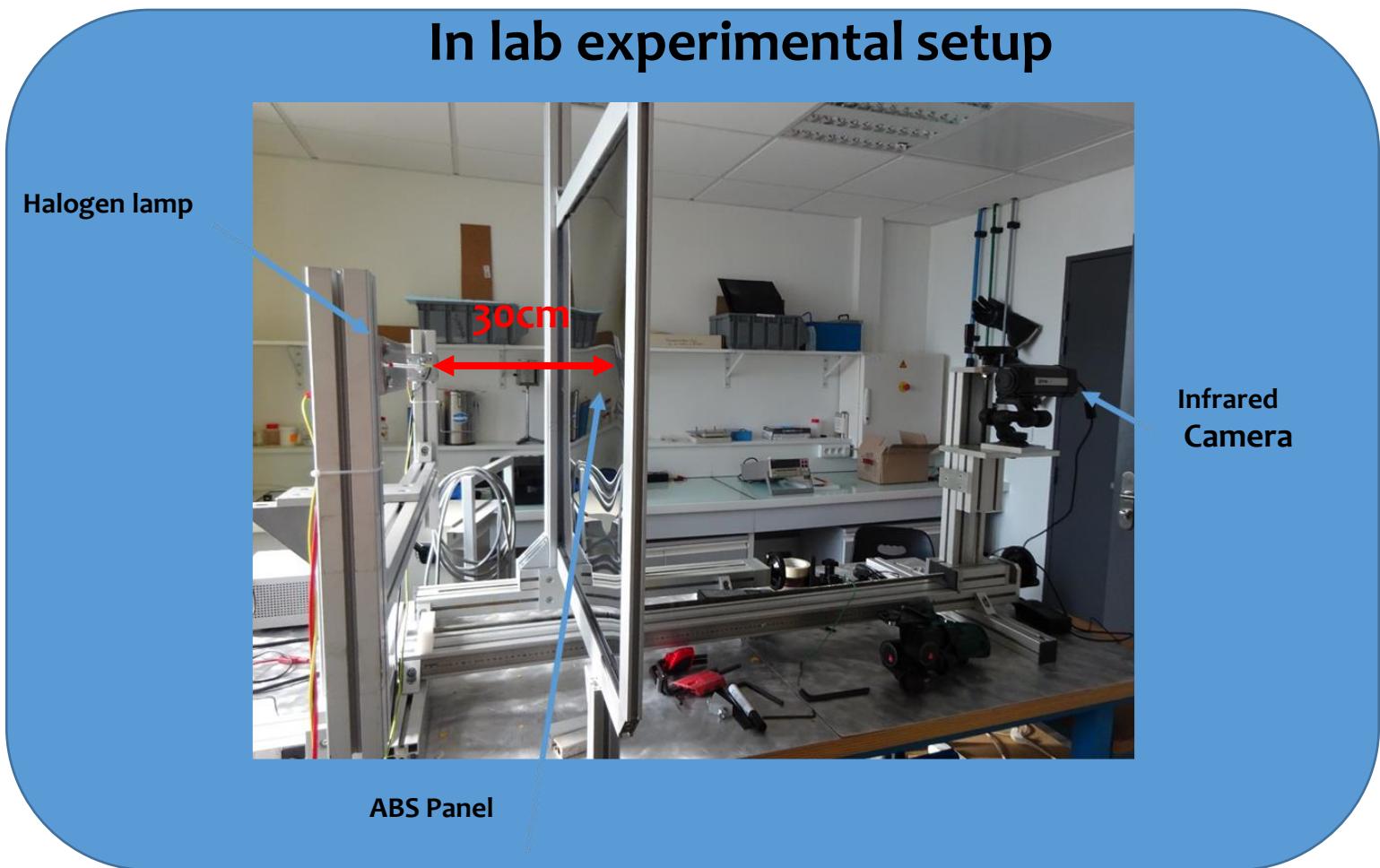
Experimental setup

- Characterisation of halogen lamps radiative emission



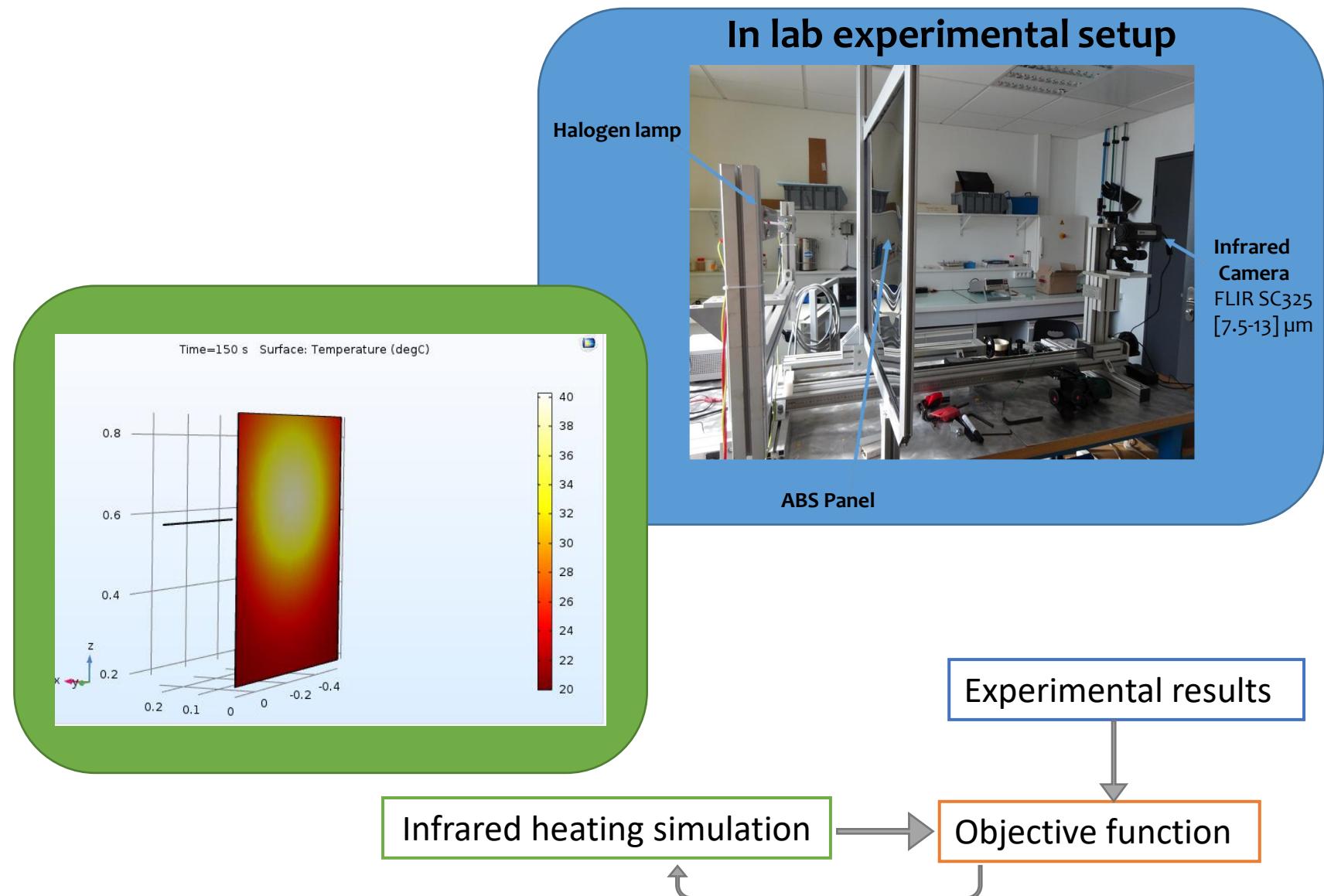
Dr. Fisher, 2000W, 400V

- Acrylonitrile butadiene styrene panel (ABS)
 - Infrared Camera :
FLIR SC325 [7.5-13] μ m



| ABS | Height | Width | Depth | Emissivity | Density | Thermal conductivity | Specific heat capacity |
|-----|--------|-------|-------|------------|------------------------|----------------------|------------------------|
| | 67cm | 68cm | 1.5mm | 0.96 | 1050 kg/m ³ | 0.19 W/(m.K) | 1300 J/(kg.K) |

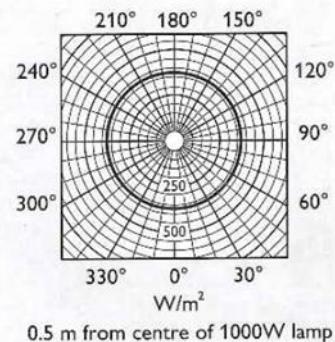
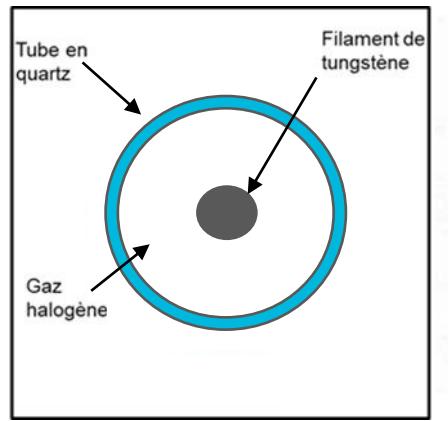
Experimental setup and inverse analysis



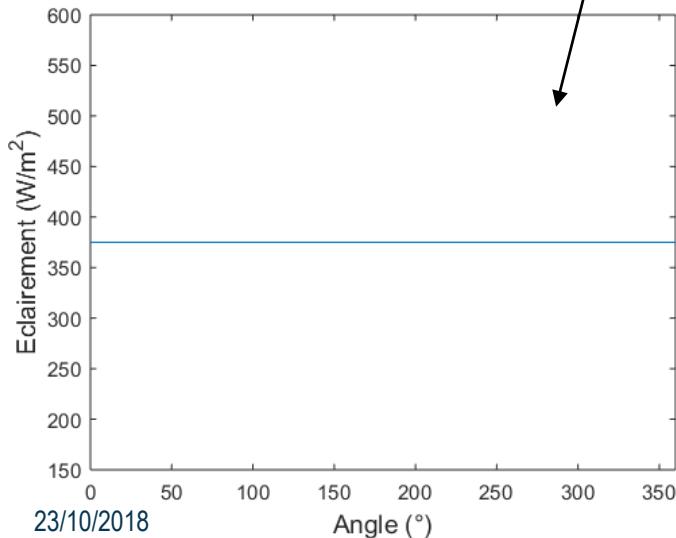
- Parameter characterisation using inverse analysis
 - Heating simulation - COMSOL Multiphysics®
 - Optimisation carried out using COMSOL Multiphysics® and Matlab®

Clear lamp vs. Integrated Reflector

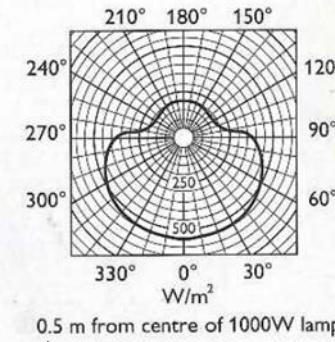
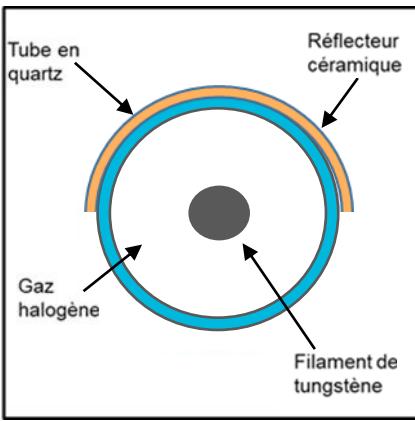
Clear lamp



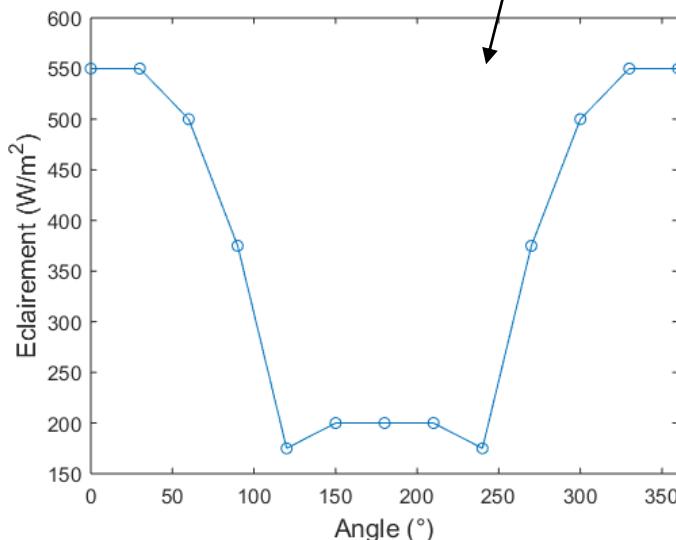
Without reflector



Lamp with Integrated Reflector



With reflector /98



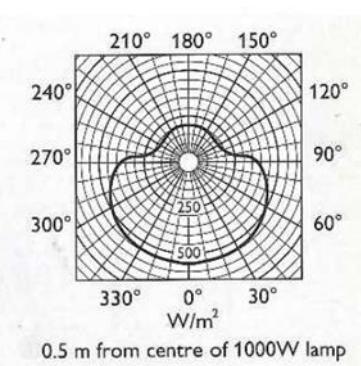
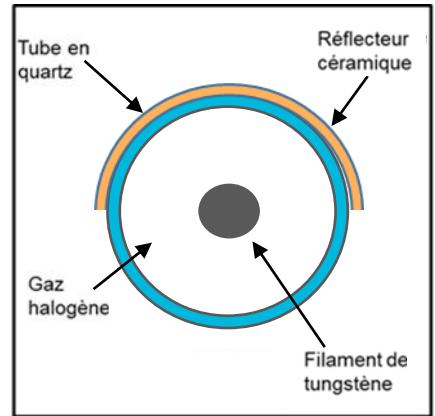
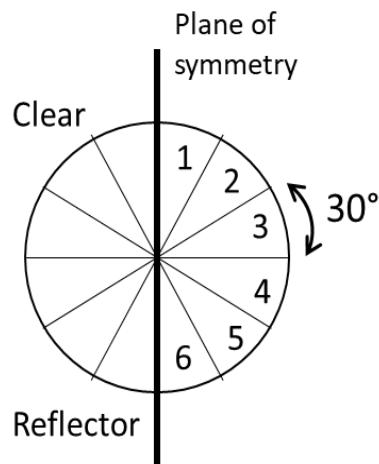
Clear lamp

- Lambertien emission
- Model
 - Equivalent cylinder
 - Filament temperature
 - Emissivity

Integrated reflector

- Coating on backside
- Non lambertien
- Model?

Integrated reflector model

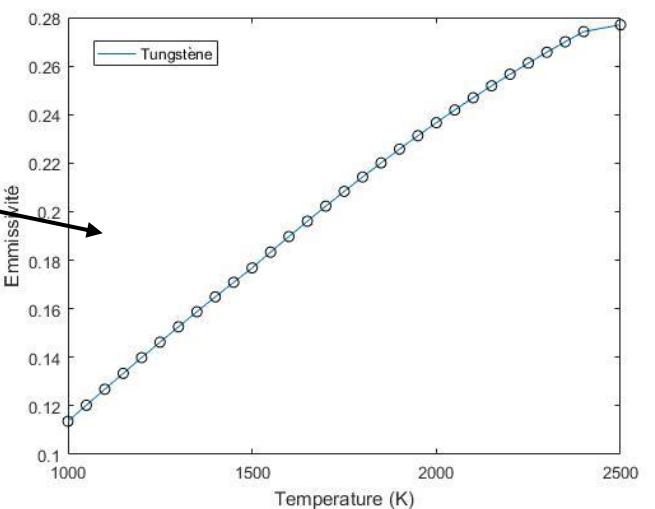


- Constant filament temperature T
- Temperature dependant emissivity ε
 - Weighted Radiosity

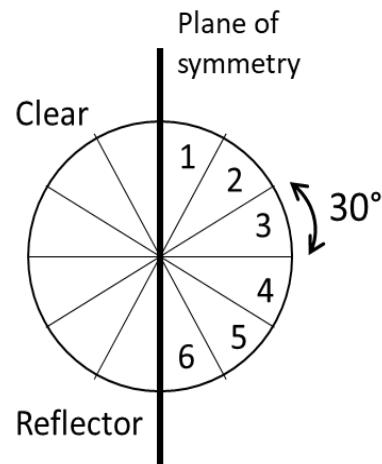
$$J_i = k_i \varepsilon \sigma T^4$$

- Conservation of emitted power

$2450K \rightarrow 2000W$



Integrated reflector: model

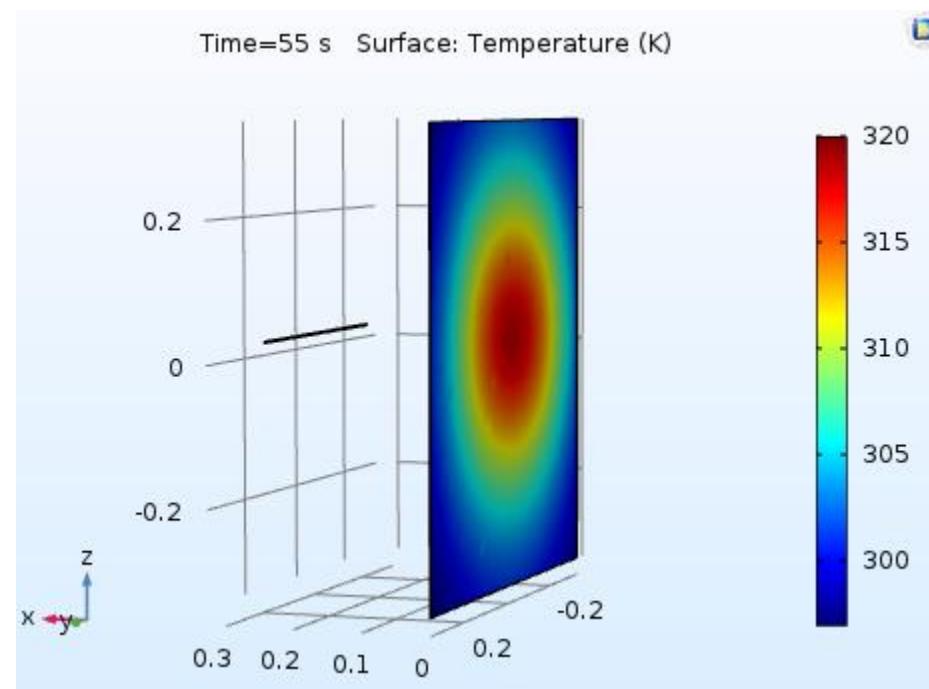


- Constant filament temperature T
- Temperature dependant emissivity ε
 - Weighted Radiosity
$$J_i = k_i \varepsilon \sigma T^4$$
 - Conservation of emitted power
$$2450\text{K} \rightarrow 2000\text{W}$$

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T)$$

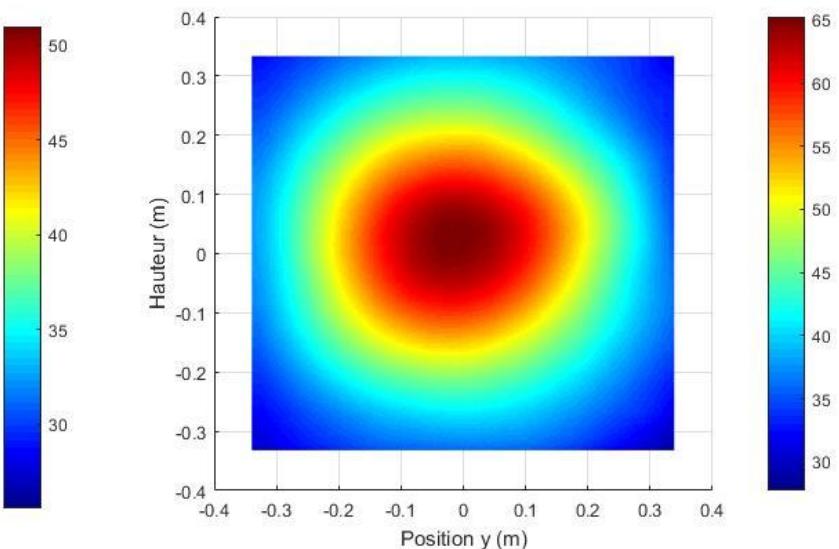
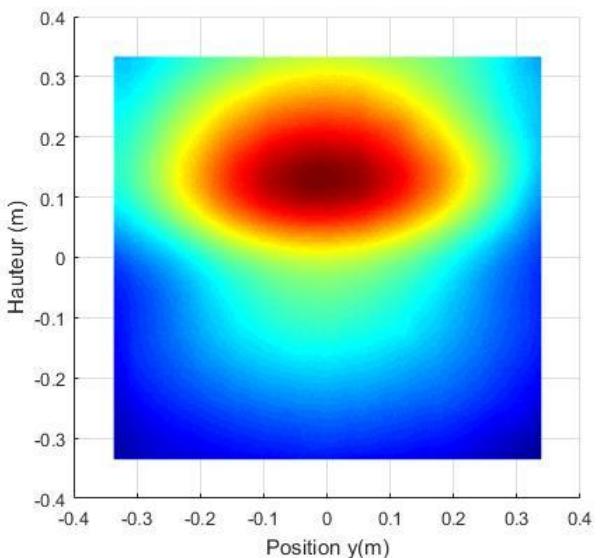
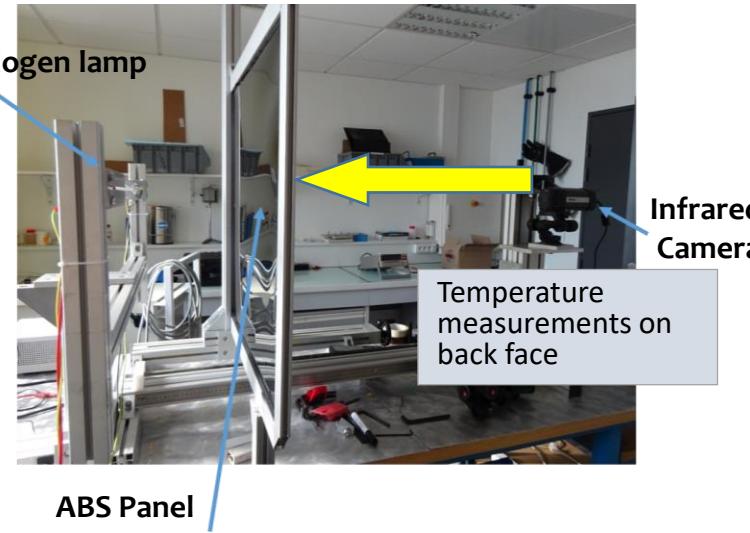
Boundary conditions

$$(k \nabla T \cdot n) = h(T_{amb} - T) + \underbrace{\varepsilon_{ABS} \sigma (T_{amb}^4 - T^4)}_{\text{Convection Radiation}}$$

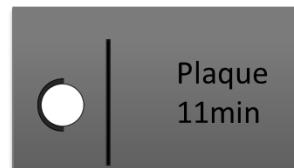


Heating simulation (COMSOL Multiphysics®). Lamp towards panel.

Experimental results

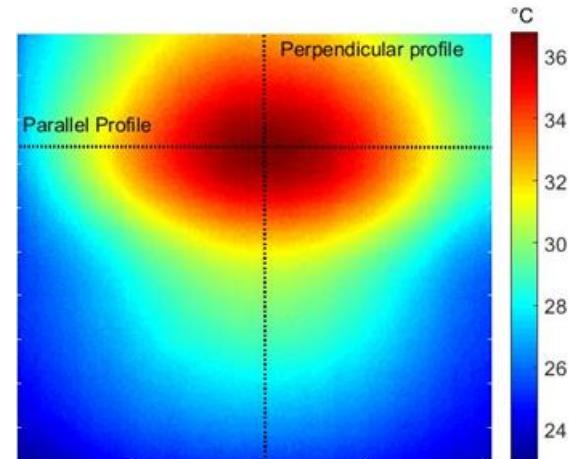
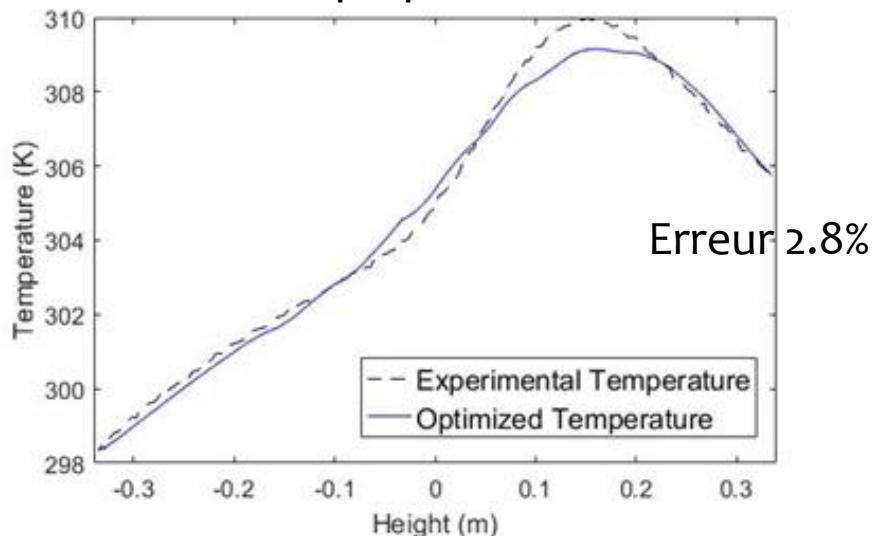


| Position | Upwards | Facing sheet |
|--------------|--------------|--------------|
| Voltage | | 400V (100%) |
| Heating time | 110 secondes | 55 secondes |



Parameter optimisation

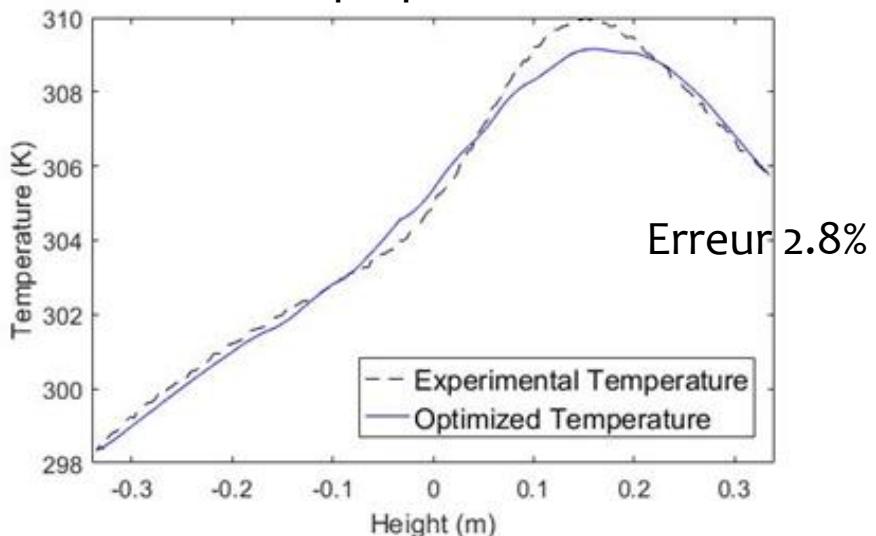
Profil perpendiculaire



| | k1 | k2 | k3 | k4 | k5 | k6 | Σk_i | Température (K) |
|------------------|---------|---------|---------|-----|-----|---------|--------------|-----------------|
| Valeur Initiale | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1 | 1900 |
| Valeur optimisée | 0.63023 | 0.19598 | 0.10211 | 0 | 0 | 0.36477 | 1.29 | 1899.9 |

Parameter optimisation

Profil perpendiculaire



- Power conservation not respected
- Coefficients not physical
- 22.6% error when used in second configuration

| | k1 | k2 | k3 | k4 | k5 | k6 | Σk_i | Température (K) |
|------------------|---------|---------|---------|-----|-----|---------|--------------|-----------------|
| Valeur Initiale | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1 | 1900 |
| Valeur optimisée | 0.63023 | 0.19598 | 0.10211 | 0 | 0 | 0.36477 | 1.29 | 1899.9 |

Parameter optimisation

- Nouveaux résultats: Cas de chauffage vers la plaque avec utilisation profil horizontal et vertical

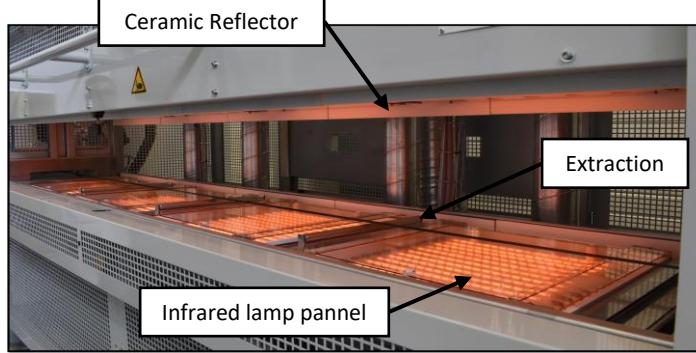
| | k1 | k2 | k3 | k4 | k5 | k6 | Σk_i | Température (K) |
|------------------|----|----|----|----|----|----|--------------|-----------------|
| Valeur Initiale | | | | | | | | |
| Valeur optimisée | | | | | | | | |

Parameter optimisation

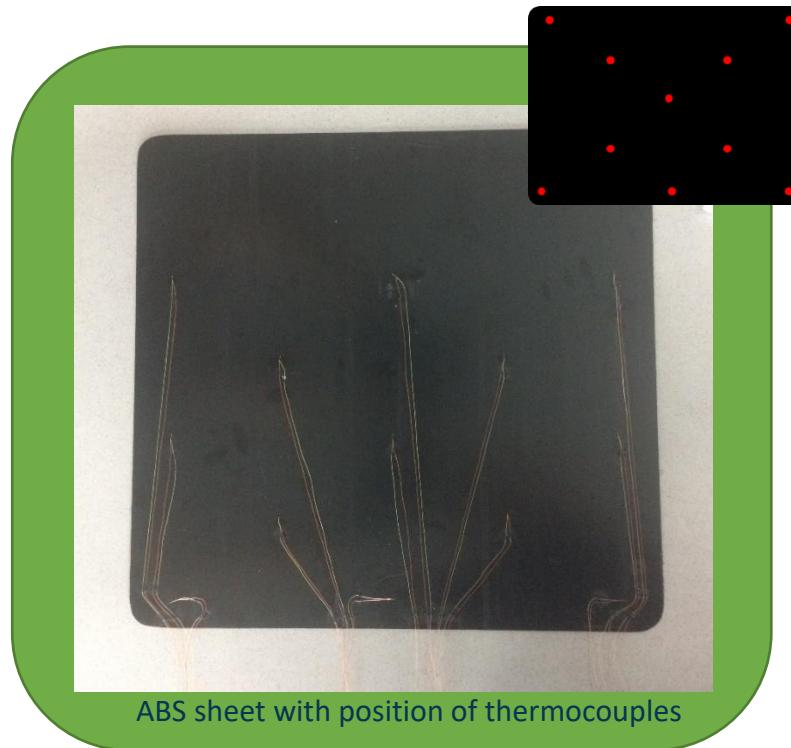
- Nouveaux résultats: Cas est utilisation profil horizontal et vertical

| | k1 | k2 | k3 | k4 | k5 | k6 | Σk_i | Température (K) |
|------------------|----|----|----|----|----|----|--------------|-----------------|
| Valeur Initiale | | | | | | | | |
| Valeur optimisée | | | | | | | | |

Experimental protocol

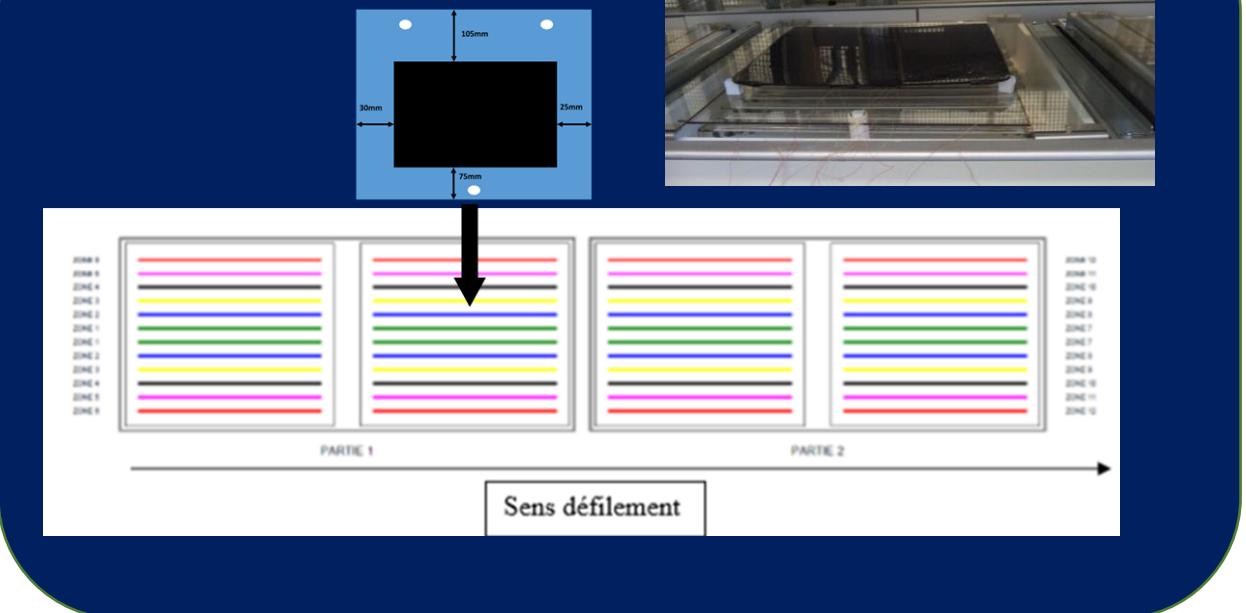


Infrared oven – Thermoplastic impregnation line (IRT SE)



ABS sheet with position of thermocouples

Experimental setup

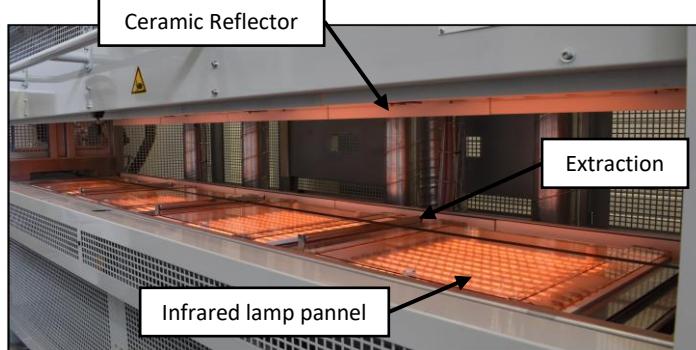


Instrumented panel

- ABS (Acrylonitrile butadiène styrène)
 - Thermocouple de type K, 80µm (x10)

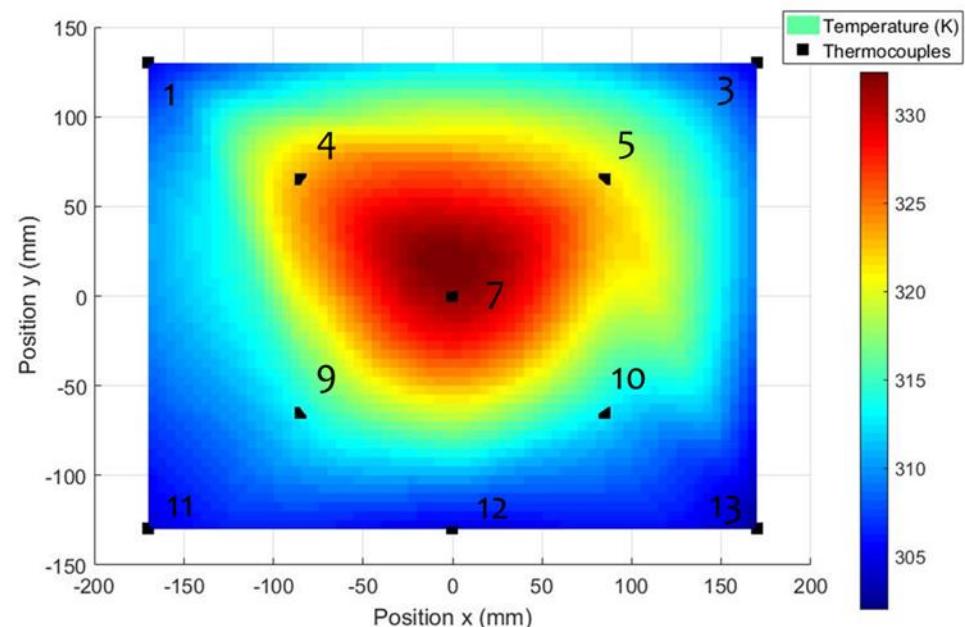
| Panel characteristics | |
|-----------------------|-------|
| Width | 398mm |
| Height | 298mm |
| Depth | 3mm |
| Depth thermocouples | 1.5mm |

Experimental results

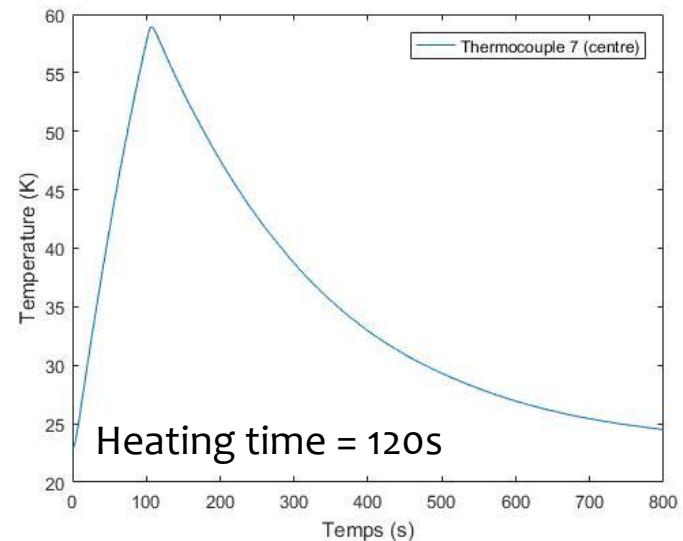


Infrared oven – Thermoplastic impregnation line (IRT SE)

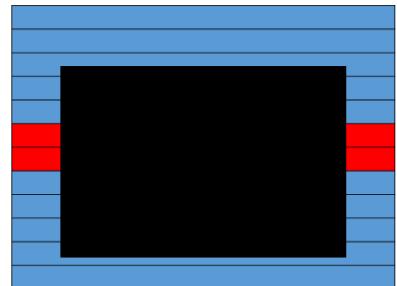
- Maximum temperature : 60°C
 - Zone 1: 4 lamps
 - Voltage: 5%
 - Circular profile similar to in lab experimental results



Reconstructed temperature field t=120s



Temperature measurement : Thermocouple 7



Heating conditions

Zone 1: 5% electrical power

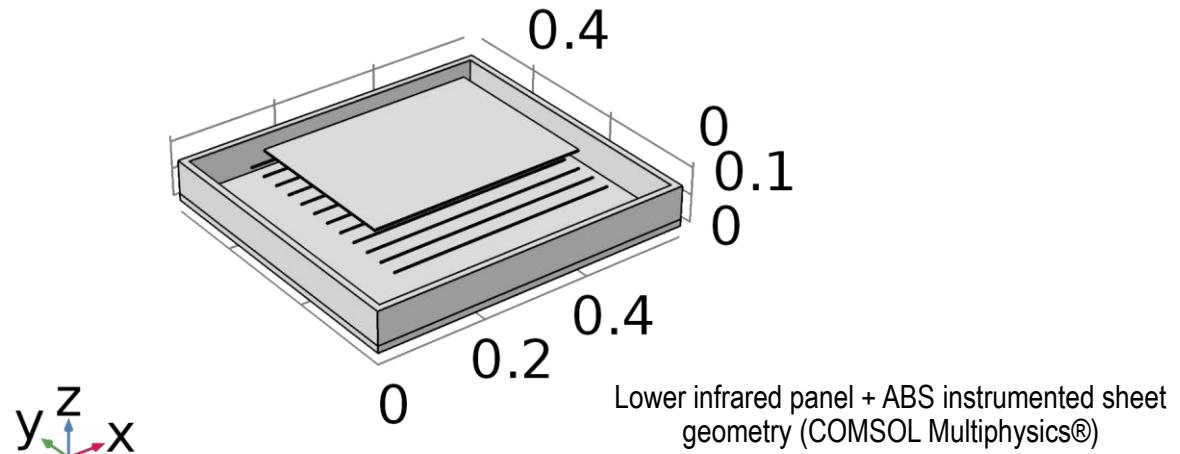
Numerical simulation

■ Geometry

- Ceramic reflectors
- Lamps
- ABS instrumented panel

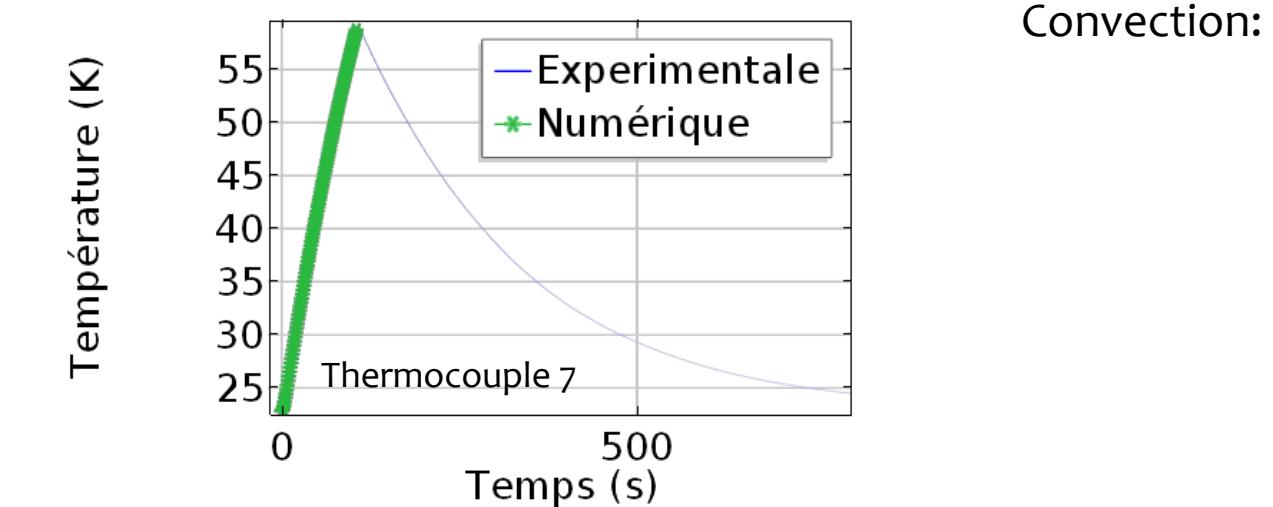
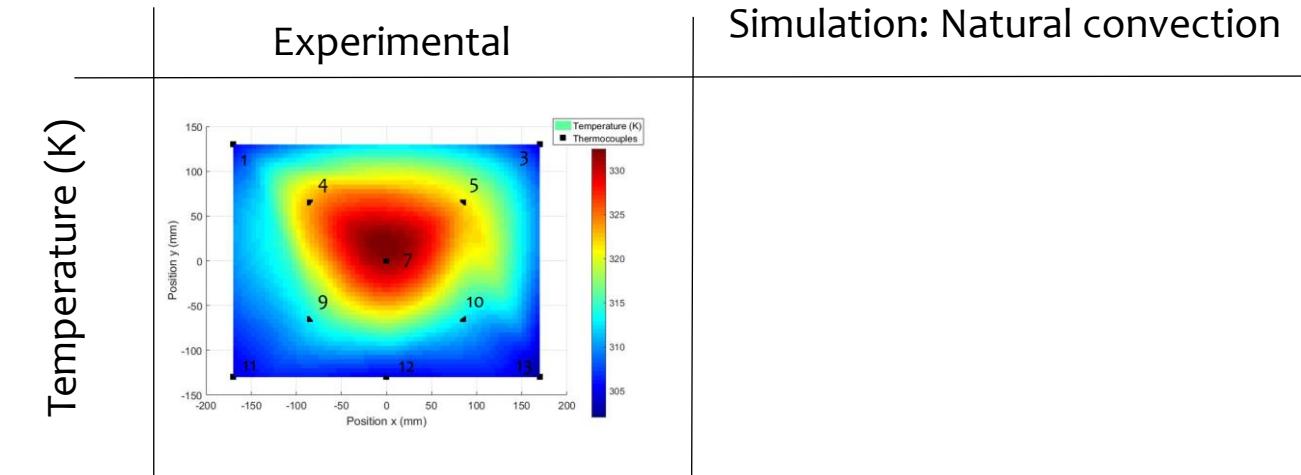
■ Lamp model: 6 zones

| | Surface | Propriétés | |
|----------------------|-------------------|--|--|
| Prescribed radiosity | 4 Lampes – Zone 1 | <ul style="list-style-type: none"> • 6 zones • Filament temperature • Filament emissivity | |
| Diffuse surface | ABS + Reflectors | <ul style="list-style-type: none"> • Emissivity | |
| Convection | ABS | <ul style="list-style-type: none"> • Ambiant temperature • Flat horizontal plate correlation | <ul style="list-style-type: none"> • Ambiant temperature • Heat exchange coefficient h [$W/(m^2.K)$] |

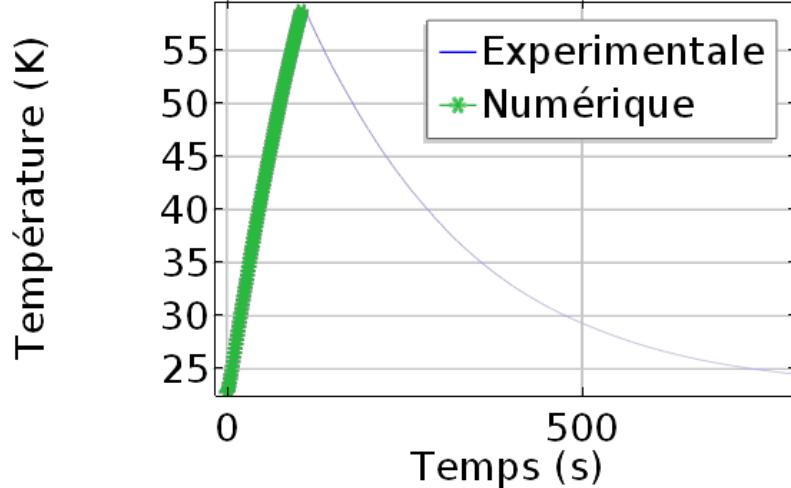
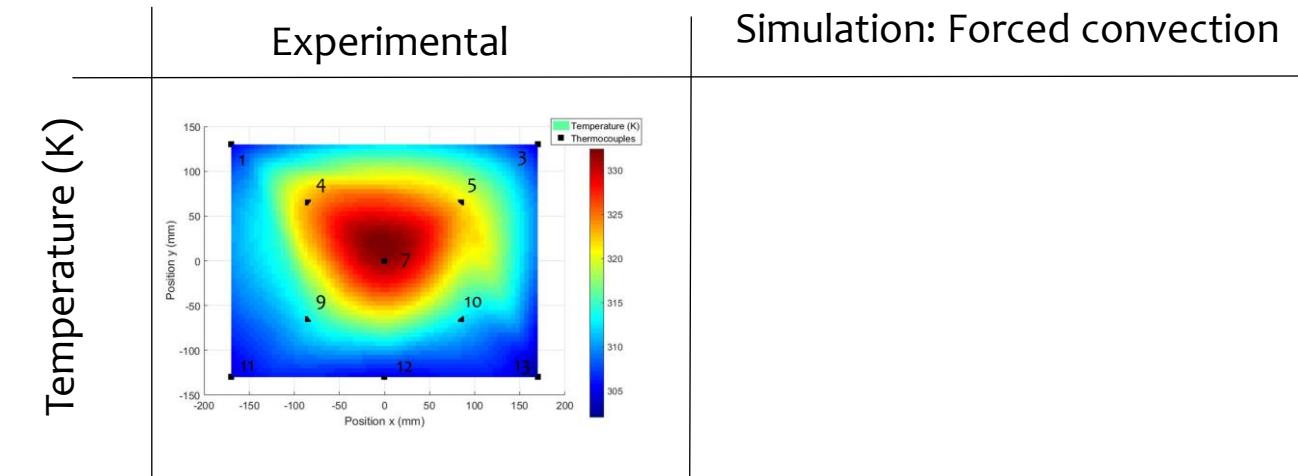


| | | ABS | Tungstène | Réflecteur |
|----------------------------|------------|------|-----------|-------------|
| Emissivité ϵ | 1 | 0.94 | $E=f(T)$ | 0.68 |
| Masse volumique ρ | kg/m^3 | 1050 | 17800 | 3900 |
| Conductivité thermique k | $W/(m.K)$ | 0.19 | 175 | 27 |
| Capacité thermique C_p | $J/(kg.K)$ | 1300 | 132 | 900 |

Comparison

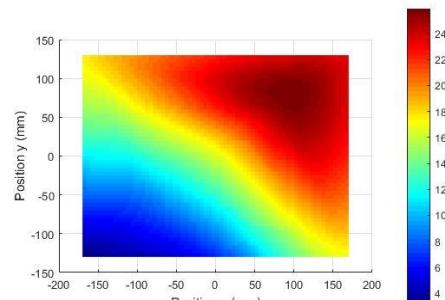


Comparison



Thermocouple 7

**Heat transfer coefficient
(W/m².K)**
Calculated from cooling step



Conclusion and perspectives

■ Conclusions

- 6 zone model for the emission of a lamp with integrated reflector
 - Inverse analysis to determine weight function
 - Good correspondence between model and experimental data
- Simulation of IR oven block
 - Implementation of 6 zone model
 - Complex convective environment

■ Perspectives

- On line experiments (Impregnation line)
 - Unidirectionel carbon fiber – PAEK prepreg characterisation
 - Convective measurements



Thank you for your attention