RADIATIVE TRANSFER THROUGH A PMMA SAMPLE. PART 2 : COMBINED TRANSFER DURING THE THERMAL DEGRADATION OF A SLAB

Jonathan Gérardin*, Zoubir Acem, Gilles Parent, Anthony Collin and Pascal Boulet
LEMTA, Université de Lorraine, CNRS
2 Avenue de la Forêt de Haye, TSA 60604 - 54518 Vandoeuvre cedex, France
* Cor. author: jonathan.gerardin@univ-lorraine.fr

ABSTRACT. This work has been carried out in order to simulate the combined heat transfer in a poly-methyl-methacrylate (PMMA) sample submitted to a high radiative flux. This corresponds to the problem of thermal degradation of a solid slab in numerous academic studies devoted to degradation and pyrolysis. The optical indices of the medium have been determined in a companion study (see Part 1). Combined radiation and conduction in a PMMA slab are considered here, providing data for the in-depth absorption of the radiative flux and the consecutive temperature profile inside the sample.

INTRODUCTION

Numerous academic studies of thermal degradation and pyrolysis of solid materials consider the case of poly-methyl-methacrylate (PMMA). This is due to particular properties related to its transformation (non-charring material, long stationary stage, good repeatability). However this material has complex optical properties as it has been demonstrated in a companion paper (see Part 1). Based on recent experiments carried out by Pizzo *et al.* [1] and Bal *et al.* [2] among others, PMMA has been observed to behave in a complex and not yet well-understood manner regarding radiative transfer. A model aimed at better quantifying the in-depth absorption and the radiation losses of the sample is required. This problem is addressed here, considering coupled conduction and radiation and boundary conditions taken from [1] and [3]. Input data (absorption coefficient and optical indices for the interface radiation modeling) are taken from the Part 1 of the present study.

CASE STUDY

The geometry is presented in Figure 1. The sample is 50 cm high, 20 cm wide and 3 cm thick. The irradiation can be provided by a specific apparatus like a FPA (Fire Propagation Apparatus which combines several tungsten lamps), or a cone calorimeter (a helicoidal coil with a conic shape which behaves almost like a black-body), or a flame itself burning at the PMMA surface. This latter case will be presented here.

The PMMA is a highly non-grey absorbing and emitting medium, with absorption coefficient computed from the absorption index (Figure 2). Very high values are reached in the mid-infrared, whereas absorption becomes weak in the near infrared and the visible. This spectral behavior has been computed in a straightforward manner from the spectroscopic data extracted from Part 1 with a very fine resolution (4 cm^{-1}). This fine resolution is kept for the radiative transfer model with no penalizing computational cost as a Monte carlo method is used, adapting the random wavenumber choices in order to fullfil the measured true flame spectral emission.

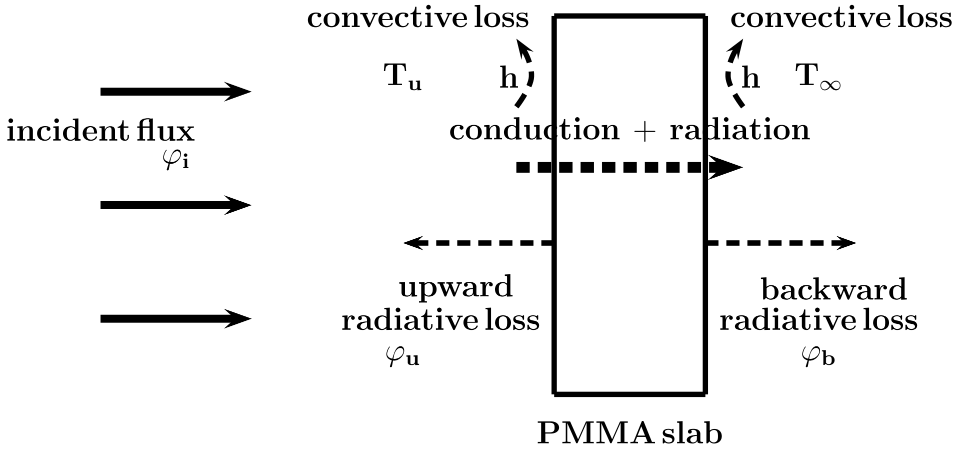

Figure 1: Sketch of the PMMA slab, with the different heat fluxes

A wavenumber is chosen and the PMMA properties are taken from the 4 cm^{-1} band around this value.

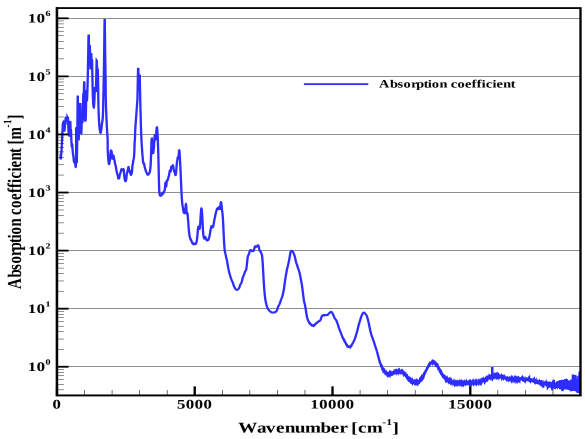

Figure 2: Absorption coefficient

For the interface reflection and refraction phenomena, Fresnel's laws have been applied, based on the optical indices identified in the companion study (see Part 1).

MODEL AND SIMULATION

A Monte Carlo Method based on an ERM reciprocal formulation (see Tessé et al. [4]) has been implemented. Up to 5.10^7 rays are launched in order to reach satisfactory convergence, based on a preliminary sensitivity study carried out on statistical results provided on the in-depth temperature and the fluxes. This model for radiative transfer has been combined with the Code_SATURN [5] in order to take account of conduction inside the sample and to introduce the boundary conditions. This code is based on a Finite Volume formulation and allows the coupling to be modeled in a straightforward iterative manner. A grid with 7500 cells is used. Convection is considered on each boundary. The spectral distribution of the irradiation due to the flame is the one measured by FTIR spectroscopy and presented in [3]. The total radiative flux in this case, obtained by integration over the whole infrared range is 14 kW.m^{-2}. The convective losses are based on a coefficient h =10 W.m^{-2}.K with a reference fluid temperature of 1445 K on the flame side (a flame temperature deduced from the FTIR spectrometer obeservation) and 300 K on the rear side. These conditions remains questionable and will receive further attention in the work in course. Complementary PMMA properties are its conductivity 0.19 W.m^{-1}.K^{-1}, heat capacity 2100 J.kg^{-1}.K^{-1} and density 1150 kg.m^{-3}. The computational scheme uses a transient approach and results will be presented for several instants, but stationary boundary conditions are considered (as for a developed flame). Therefore, results will not be studied during the early stage since the flame development is not included in the boundary conditions. Initial temperature is 300 K for the whole plate.

NUMERICAL RESULTS

The temperature profile inside the sample is presented in Figure 3 for different instants (after 600, 1200 and 1800 s), the plate being irradiated by the flame developed along its upward face.

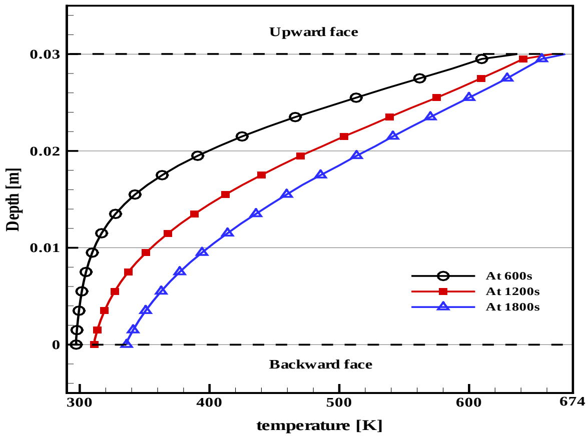

Figure 3: Temperature profiles inside the sample

The temperature increases with time due to the flame irradiation, with a strong absorption just below the irradiated surface (due to a high average absorption coefficient). The temperature evolution is obviously non linear and cannot be captured with simple approximations. The upward face temperature reaches 674 K after 1800 s, which is in a remarkable agreement with the experiments carried out with an IR camera [3]. However, remember that the boundary conditions would need further attention and at least a dedicated sensitivity study. Further study would allow to evaluate the deviation of the present in-depth absorption as compared to often used approximations (black surface, Beer's law or Rosseland's approximation often encountered in the literature devoted to PMMA degradation studies).

CONCLUSION

A simulation of the combined radiative and conductive transfer inside a PMMA slab has been carried out. Input data taken from a dedicated sprectrospic study have been introduced and heat transfer during a sample degradation study has been simulated. Results for the temperature reached by the irradiated surface are in good agreement with available experimental data. Further tests will be conducted in order to check the ability of the present model to describe the behaviour of this non grey material.

REFERENCES

[1] Y. Pizzo *et al.*, ", *Combust. Flame*, vol. 156, pp. 1856–1859, 2009.

[2] N. Bal *et al.*, "Experimental study of radiative heat transfer in a translucent fuel sample exposed to different spectral sources", *Int. J. Heat Mass Transfer*.

[3] G. Parent *et al.*, ", *J. Phys. : Conf Series*, vol. 395, no. 012153, 2012.

[4] L. Tessé *et al.*, ", *Int. J. Heat Mass Transfer*, vol. 47, no. 3, pp. 555–572, 2004.

[5] F. Archambeau, N. Méchitoua, and M. Sakiz, "Code_ Saturne : a Finite Volume code for the computation of turbulent incompressible flows - Industrial applications", vol. 1, 2004.