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Radiation emission from a heating coil or a halogen lamp on a semitransparent sample

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ABSTRACT

The radiation emission of the heating coil of a Cone Calorimeter and the one of the halogen lamp of a Fire Propagation Apparatus have been studied experimentally for varying power settings. These are two standard apparatuses used for fire calorimetry. The objective is to characterize and compare the radiative flux spectrum received by a fuel sample during pyrolysis experiments. The deviation from the standard assumption of black or gray emission is discussed. It is observed that the emission of the heating coil can be approximated well to an ideal blackbody, especially in the infrared range. On the contrary, the halogen lamp emission is more complex, non gray, with an important contribution in the visible and in the near infrared ranges. The flux received by a sample exposed to these emitters is predicted using ray tracing simulations. This shows that the irradiation flux and spectrum from the cone can be accurately calculated if the coil temperature is known. The non Lambertian irradiation flux from the lamp is modeled with a combination of diffuse and collimated intensities, representing the direct emission from the lamp itself and the reflection by the mirror at the rear side. For both emitters, the irradiation is confirmed to be approximately uniform over the surface of a sample 5 cm large (maximum deviation of ±2% on the incident flux). The uniformity decreases for larger samples, but the ratio of the flux at the center to average flux is still 1.04 for standard 10 cm × 10 cm samples under the cone. For illustration purposes, the influence of the spectral characteristics of the emitter is studied in the case of a sample of PMMA, a non gray translucent medium. Using recently published measurements of PMMA absorptivity, the absorbed flux by a 3 cm thick sample is predicted. In the case of an incident flux of 20 kW/m^2, the calculated average absorptivity of the sample is 0.91 under the cone, while it is 0.32 under the FPA lamp. These calculations involve absorption data of a virgin sample at room temperature and consequently the numerical results only hold for the initial instants of irradiation. However, the very large differences in radiative behavior show that important discrepancies in the pyrolysis behavior are expected between the two emitters. This might have consequences for fire testing and inter comparisons of flammability results worth further investigation.

1. Introduction

Pyrolysis and ignition characterization of fuels are key problems in fire sciences, aimed at providing source terms for the propagation studies. Experimental studies on that point have been conducted for decades on every types of possible fuels. Most of them involve a high heat irradiation on a sample, making the radiative transfer of primary interest for the understanding of the degradation process. As a logical consequence, the type of emitter has been long identified as possibly influencing the determination of pyrolysis and ignition parameters. It is for example recalled in the SFPE Handbook of Fire Protection Engineering [1] that there is a difference between the near gray continuous emission from panels or heaters in the range 700–1000 °C and high temperature lamps with so-called radiative temperature of 2200–3000 °C. The spectral distributions of the corresponding emissions are known to be different with possible consequences for the study of the material degradation when submitted to the incident radiation. Despite this observation, few studies involve a preliminary spectral characterization of the emission source. A blackbody or a gray-body behavior are generally assumed for the radiation source and the received heat flux is evaluated from a heat flux gauge which accounts for

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Nomenclature

F_{fl}	view factor between fluxmeter and lamp (–)
I_{bb_ν}	blackbody spectral intensity (W m^{-2} sr^{-1} cm)
I	total intensity (W m^{-2} sr^{-1})
I_ν	spectral intensity (W m^{-2} sr^{-1} cm)
S_f	fluxmeter surface (m^2)
S_l	lamp surface (m^2)
T	temperature (K)

Greek symbols

α	absorptivity (–)
β,	angle (rad)
ε_W	tungsten emissivity (–)
φ,	flux density (W m^{-2})
τ_q	quartz transmissivity (–)
Ω_0	solid angle of incidence (sr)

Subscripts, superscripts

col	collimated
dif	diffuse
lamp	lamp property
meas	measured property

List of abbreviations

CC	Cone Calorimeter
FPA	Fire Propagation Apparatus
PMMA	Poly-methyl-methacrylate

geometrical concerns but which evaluates the total heat flux with no spectral consideration. A complete review on degradation studies is not carried out here. Some selected papers are only discussed below, but recent contributions by Girods et al. [2] and Bal et al. [3] refer to successive studies which already demonstrated that the heater type, or the geometrical configuration (and consequently the view factor), or the sample surface properties, all affect the degradation results (see Hallman [4] who observed differences in the ignition delay time when using different heat sources, or Thomson and Drysale [5] who studied the influence of the heater-sample distance, among others). Försth and Roos [6] measured the spectral absorptivity of a panel of 62 different materials. By using Planck's averaging with various blackbody temperatures they showed that the absorptivity does not only depend on the material but also of the radiation source. It is because of this identified difficulty that the standards involving the FPA also clearly indicate that samples need to be coated with high emissivity inert paint to ensure the heat flux measured during the gage calibration will be the value absorbed by the sample surface. However some studies [7,8] showed that infrared radiation is not fully absorbed. In-depth absorption still occurs. Up to 65% of radiation could be transmitted by a standard carbon coating according to [7]. Moreover, despite the very small mean free path of radiation through some materials, important transmission still occurs through very fine samples. Finally, the coating alters the true behavior of the material and a knowledge of its properties is still of interest. In particular, even after surface absorption, radiative transfer inside the sample through absorption/emission processes still requires the knowledge of material properties. The present work is consequently focused on the characterization of the spectral emission by two usual devices and on the absorption properties of a typical semi-transparent sample, in order to evaluate the absorbed flux in various conditions. The study is carried out on the raw sample and provides results for the first instants of the irradiation, with a fine evaluation of spectral effects in particular.

Two of the most widely used heaters for benchscale tests are the Cone Calorimeter and the Fire Propagation Apparatus lamps [9,10]. The cone is based on a helicoidal coil which simply emits like an electric heater and has a truncated cone shape. The FPA lamp is made of several tubular quartz bulbs each holding a high temperature tungsten filament, located in parallel in a parallelepipedic box. At the rear of the box a mirror-like surface reflects the radiation toward the forward hemisphere. A quartz window closes the box on the front face, allowing to transmit the radiation emitted by the bulbs. This provides a complex emission pattern schematically coming from a rectangular surface, but due to the tungsten filaments and modified by reflection and transmission processes.

Although the FPA exhibits a complex and non fire-like emission spectrum it has other advantages. For example the combustion gases never come into contact with the heat source in the FPA, whereas they do in the Cone Calorimeter. The flow conditions in the FPA are also more quiescent and better controlled than in the Cone Calorimeter. Considering their respective advantages, both methods are used in studies devoted to material characterization.

In the present work, the emissions provided by each source were characterized, in order to compare their emission distribution (in terms of direction and wavelength) and to discuss the consequence for a given sample of using one or the other emitter. Bal et al. [3] already demonstrated on a particular case (fixed power supply for each emitter) how the spectral distributions may be different. Reference [3] presents total transmissivity measurements through PMMA samples obtained using a heat flux gauge and considers spectral properties for a qualitative analysis which reveals the complexity of the spectral analysis. Average properties were sought but one of the conclusions is the necessity of undertaking a fine spectral description. This was indeed the basis of the present paper. In the present work the emission study is extended to various power supplies for both apparatuses, characterizing the cone and the lamp emission for a wide range of provided heat fluxes. It starts with the complete characterization of the radiative sources for several set points, also explaining how they can be modeled. Then it addresses radiative transfer simulation through a Monte Carlo model for a fine spectral directional study. A deeper knowledge of the spectral emission is provided, with information given on how it varies for several characteristic source temperature in particular. The experimental method uses a setup previously involved in Boulet et al. [11] where the heating coil of a first Cone Calorimeter was observed to behave close to a blackbody. One important strength of the setup is that it provides spectral data instead of a unique total flux that may hide strong variations as a function of the wavelength. Studies have been conducted here on the spectral characterization of the emission by the heating coil of a Cone Calorimeter for three different heat flux set points on the one hand, on the characterization of a FPA lamp under six different power supplies on the other hand. As above stated, the absorptivity of the studied sample governs in a complex manner the absorbed flux, especially in the case of a non gray absorbing sample. This is illustrated in the present work by considering the particular case of a 3 cm thick clear PMMA (poly-methyl-methacrylate) sample, which spectral absorptivity has been measured. PMMA is involved in numerous studies devoted to thermal degradation and has become a standard sample. It is a good candidate for the present purpose since it is semi transparent with strong variations of its spectral absorptivity. In the present paper the absorbed fluxes will be compared when irradiation comes from the cone or the FPA lamp. Results only hold for the first instants of the irradiation because PMMA is known to be quickly altered with a modification of the surface emissivity and with the appearance of bubbles