Wildland-Urban Interface Virtual Essays Workbench WUIVIEW GA number 826522

PBD Virtual Lab WUIVIEW

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WUIVIEW – Presentation of the different benches and devices

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Abstract	This document details the characteristics of the main experimental benches and the different acquisition systems of IMT Mines Alès ARMINES. A first focus is done on a calorimetric cone. Then, two specific equipment designed at IMT Mines Alès (RAPACES 1.1 and 1.2) will be presented. Equipment related to field tests is presented. This document ends with a list of sensors and acquisition devices.

(1) Draft / Final
(2) Public / Restricted / Internal

Content

1. Introduction

This document describes the facilities, equipment and instrumentation of ARMINES/IMT Mines Ales/LGEI/Institute for Risk Science.

The risk team of IMT Mines Alès was created in 1996 and counts today 9 researchers and 2 technicians. The team is divided in three research axis; one of them is devoted to Physics of Phenomena topics. The Institute for Risk Sciences was built in 2010. In 2015 was added the Spark Facility aiming to perform fire and explosion tests at small scale.

The team Physics of Phenomena is skilled in performing large scale tests about industrials hazards (fire; explosion; liquid or gas release; marine pollution). Most tests were performed on independent test sites located worldwide (Germany, United Kingdom, Italy, Belgium, Argentina). The following pictures illustrate typical experimental field tests performed by the team Physics of Phenomena. Figure 1 and 3 were performed to characterize the impact of radiative heat flux of forest fire on LPG Tank (Figure 1: on Alès test site, Figure 3: on GL Nobel Test site). The test presented on Figure 2 is a propane vapour cloud explosion performed on military camp.

Figure 1. Test of wooden fence fire on LPG tanks

Figure 2. Propane vapor cloud explosion tests

Figure 3. Gas fueled burning wall impacting an LPG tank

Besides from these outdoor large scale tests, the Institute for Risk Science has small and medium scale equipment aiming to characterize fire hazard. The list of equipment and prototype related to fire will be described in following sections. Equipment dedicated to other research subjects (explosion for instance) are not presented in this document.

Figure 4. Institute for risk Science, Alès (ARMINES/IMT Mines Alès/LGEI)

2. Small scale bench: calorimetric cone

This apparatus aims to measure the heat release rate (HRR) of a sample at different external irradiance. This apparatus complies with the ISO 5660-1:2002(E) standard. The test method is based on the observation that, generally, the net heat of combustion is proportional to the amount of oxygen required for combustion. The relationship is that approximately 13.1 MJ of heat are released per kilogram of oxygen consumed. Specimens in the test are burned under ambient air conditions, while being subjected to a predetermined external irradiance within the range of 0 kW/m^2 to 100 kW/m^2 and measurements are made of oxygen concentrations and exhaust gas flow rates.

The test method is used to assess the contribution that the product under test can make to the rate of evolution of heat during its involvement in fire. These properties are determined on small representative specimens. A schematic representation of the apparatus is given in Figure 5.

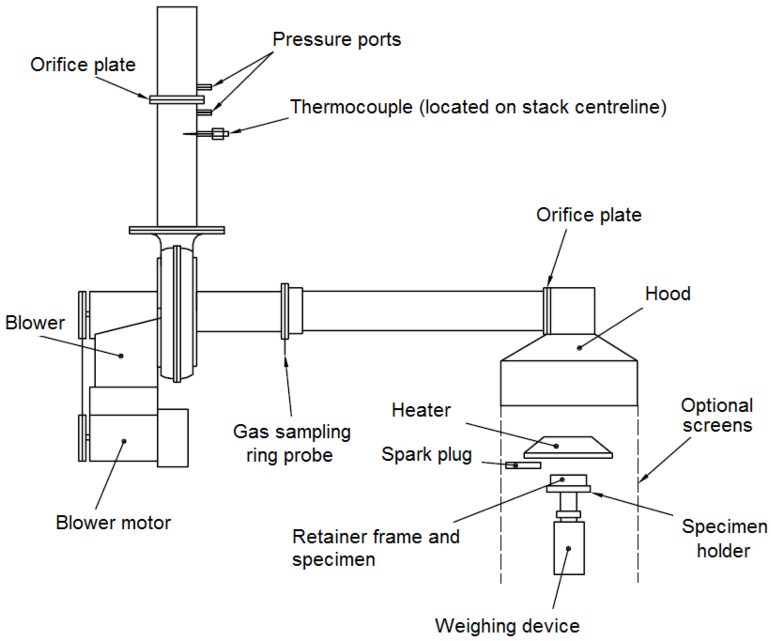

Figure 5. Apparatus

2.1. Description of the apparatus

The active element of the heater consists of an electrical heater rod, capable of delivering 5 kW at the operating voltage, tightly wound into the shape of a truncated cone (see Figure 6). The heater is encased on the outside with a double-wall stainless-steel cone, filled with a refractory fiber blanket of nominal thickness 13 mm and nominal density 100 kg/m^3.

The irradiance from the heater is maintained at a preset level by controlling the average temperature of three thermocouples (type K stainless-steel sheathed thermocouples) symmetrically positioned and in contact with, but not welded to, the heater element. The heater is capable of producing irradiance on the surface of the specimen of up to 100 kW/m^2. The irradiance is uniform within the central 50 mmx50 mm area of the exposed specimen surface. An illustrative picture of the burning area is given in Figure 7.

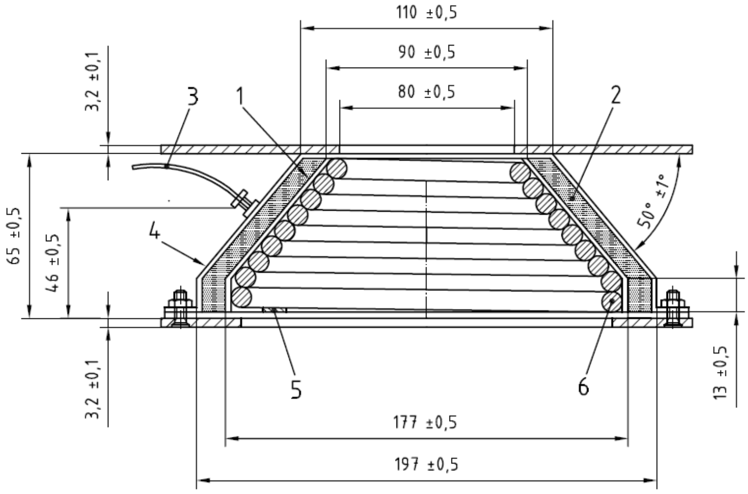

Figure 6. Cone heater

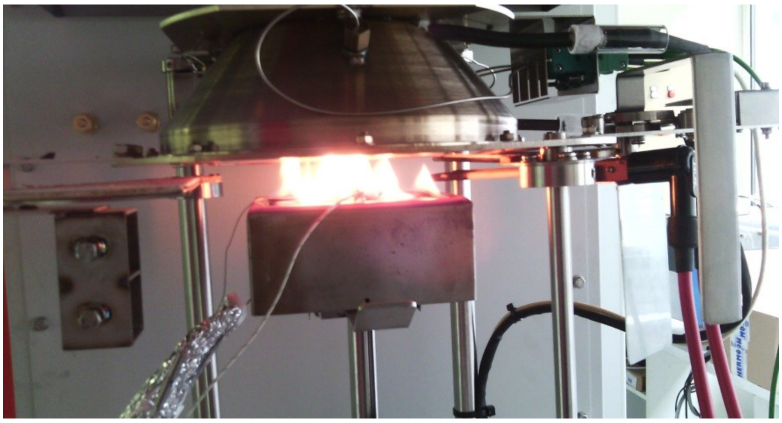

Figure 7. Test example

The smoke is vented by a fan and sampled by a specific apparatus.

2.2. Gas sampling apparatus

The gas sampling apparatus incorporates a pump, a filter to prevent entry of soot, a cold trap to remove most of the moisture, a by-pass system set to divert all flow except that required for the gas analysers (O_2; CO and CO_2), a further moisture trap and a trap for CO_2 removal.

The oxygen analyser is paramagnetic type. Since oxygen analyser is sensitive to stream pressures, the stream pressure is regulated (upstream of the analyser) to minimize flow fluctuations and the readings from the analyser are compensated with an absolute pressure transducer to allow for atmospheric pressure variations. The analyser and the absolute pressure transducer are located in an isothermal environment.

2.3. Heat flux meter

The working heat flux meter is used to calibrate the heater. It is then positioned at a location equivalent to the centre of the specimen face during this calibration. This heat flux meter is Schmidt - Boelter (thermopile) type with a design range of 0 to 100 kW/m^2.

2.4. Data collection and analysis system

The data collection and analysis system are recording the output from the oxygen, carbon monoxide and carbon dioxide analysers, the orifice meter, the thermocouples and the weighing device. The system is capable of recording data every second.

2.5. Operating procedure and HRR determination

The operating procedure is well described in the standard ISO 5660-1:2002(E) and is rigorously followed during an experiment.

3. Medium scale bench: RAPACES

An innovative experimental setup based on cone calorimeter device has been designed at IMT Mines Alès. This new device allows testing sample whose size may be 10 times bigger than that of a cone calorimeter sample.

The heat source can be set at various orientations: vertical and horizontal. Both configurations will be described. RAPACES 1.1 corresponds to the vertical configuration; RAPACES 1.2 corresponds to horizontal configuration. The heat source electric supply, instrumentation and data acquisition are common to both configurations.

3.1. Description of the apparatus RAPACES 1.1 (vertical sample)

This apparatus is composed of different parts: a radiant panel, a radiant concentrator of thermal flux, a test chamber and security components. A scheme of this apparatus with the different parts is exposed on Figure 8. A picture is given on Figure 9.

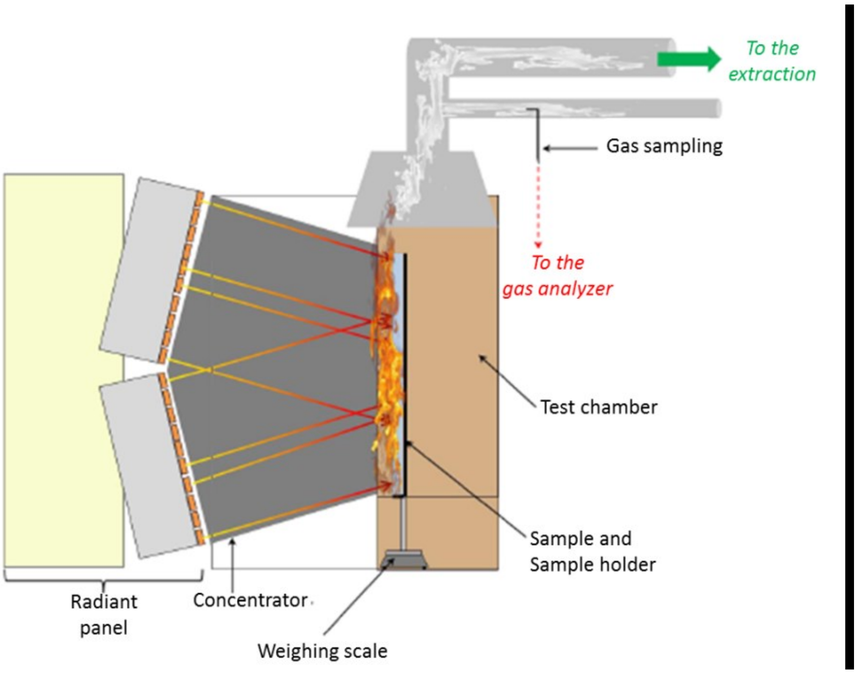

Figure 8. Description of RAPACES 1.1 experimental setup

Figure 9. Picture of RAPACES 1.1 experimental setup

3.1.1. Radiant panel

The radiant panel has been manufactured by Chaudelec company (France). Maximum electrical power of the panel is 120 kW. In the most common configuration, the radiative surface is composed of two 60 kW panels, producing an emitted heat flux of 118 kW/m^2. The panels are made of 3kW short-wave infrared halogen lamps.

For a lamp set at its maximum operating power, the filament temperature is 2700 K (supplier data). Figure 10 illustrates the variation of the temperature of the tungsten filament of IR lamps according to the percentage of nominal power assigned to the lamps. Data are taken from Nakousi (2012)[1].

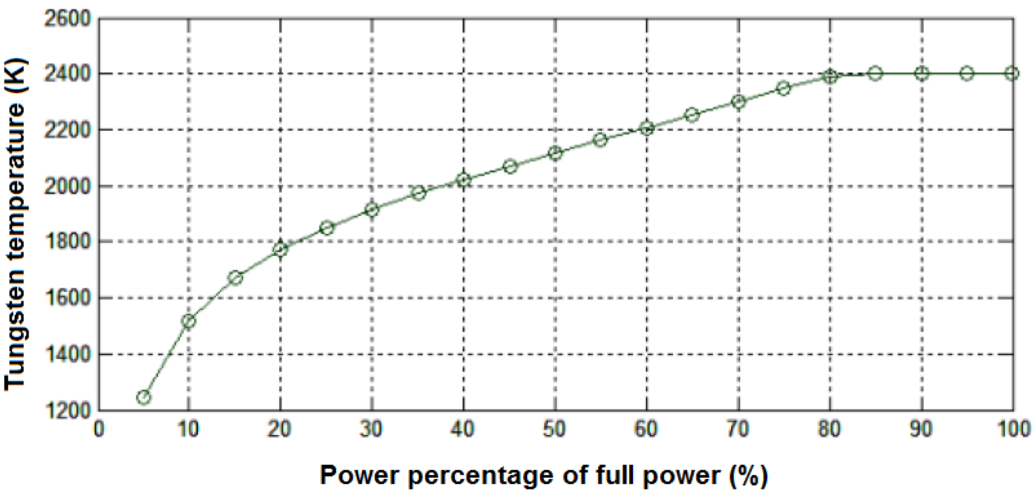

Figure 10. Variation of tungsten temperature as a function of power supply (Monteix[2])

[1] S. Nakousi (2012) Modélisation du procédé de cuisson de composites infusés par chauffage infrarouge, thèse de doctorat, université de Toulouse, France

[2] S. Monteix (2001), Modélisation du chauffage convecto-radiatif de préformes en P.E.T. pour la réalisation de corps creux, thèse de doctorat, ENSMP

From a radiative point of view, the spectral emissivity of tungsten is dependent on its temperature. It has been characterized on short wavelengths (from 0.24 µm to 2.6 µm). Latyev et al[3]. present the values of the spectral emissivity in the 0.4 to 4 µm band.

For higher ones (greater than 5 µm), Monteix has established the spectral emissivity curve of tungsten as a function of its temperature as shown in the following figure. Spectral emissivity is described by the approximated Hagen-Rubens model. Emissivity decreases as the wavelength increases. In Figure 11, the curves intersect at a point around 1.3 µm. At this point, the emissivity of pure tungsten does not vary with temperature. The integrated emissivity of tungsten for the temperature of 2900 K on the 0.25 - 28 µm band is estimated at 0.304.

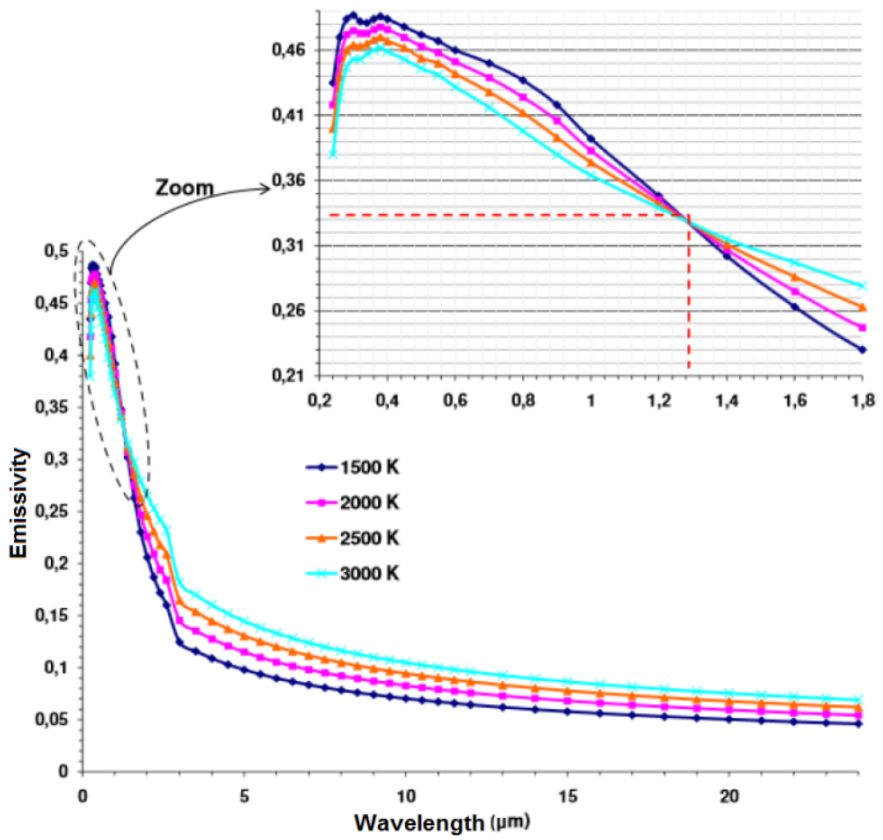

Figure 11. Spectral emissivity of tungsten (Monteix)

3.1.2. Thermal flux concentrator

The concentrator has been designed at IMT Mines Alès (Figure 9). Four polished stainless steel plates constitute a tunnel (1m long) between the source and the sample to lead the radiative heat flux to the sample location. Using a radiative heat fluxmeter, it was checked that the heat flux received by the sample was almost uniform. Thanks to this concentrator, the maximum heat flux received by the sample is around 80 kW/m².

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[3] L. N. Latyev, V. Y. A. Chekhovshoi, and E. N. Shestakov (1970), "Monochromatic emissivity of tungsten in the temperature range 1200-2600 K and in the wavelength range 0.4-4 µm," High Temp. High Press., vol. 2, pp. 175–181.

3.1.3. Test chamber

The test chamber is the location of the combustion. Its dimensions are 900mm (L) x 900 mm (L) x 2000 mm (H). Three walls are made of aerated concrete. This test chamber is connected to an exhaust hood to evacuate the smoke (Figure 9).

All kind of material can be tested with this apparatus: plastic, wood, textile… The size of the sample is between 100 cm² and 4900 cm². For the largest areas (between 2500 and 4900 cm²), only textiles can be tested for safety purpose. However, these largest areas can be tested also for plastic and wood if the exhaust hood has a sufficient air flow to evacuate the generated smokes.

The sample holder consists of two wire meshes held rigidly on their sides by metal rods to prevent the thermal expansion of the grids. The sample is sandwiched between the two wire meshes. The meshing size is 12.5 mm by 12.5 mm, while the wire diameter is 0.5 mm. Dimensions of these two grids vary depending on the sample surface. This assembly is positioned on a metal structure guiding the sample holder along axes parallel and perpendicular to the source. A steel receptacle (50 x 10 x 2 cm^3) is located below this structure to recover all dripping residues during combustion. The sample holder enables reproducing a fire scenario where the two sides of a plate are “free conditions” (no insulation at the rear face). This sample holder allows assembling several materials juxtaposed and/or superimposed during a same test in order to simulate representative assembling of materials (coating, plaster and concrete).

A shutter is placed at the exit of the concentrator at the beginning of the test. It protects the sample before the test to obtain a maximum flux from the IR lamps (pre-heating time). This shutter allows obtaining a stable initial weight of the sample and gives time to the operator for checking before the beginning of the test. This shutter is especially important with highly inflammable samples.

3.2. Description of the apparatus RAPACES 1.2 (horizontal sample)

The main objective of RAPACES 1.2 is to test the influence of the horizontal orientation of the radiative source on a horizontal sample. This new configuration has the characteristics of RAPACES 1.1 in terms of flux emitted by the radiative source, sample size and heat flux received by the sample. The power of the radiant panels (3 kW x 40 lamps) is therefore identical to that used during the tests at RAPACES 1.1. On the other hand, the sizing of this new prototype presents some design differences. A sketch is given on Figure 12; a picture is given on Figure 13. A detailed sketch of radiant patterns is given on Figure 14.

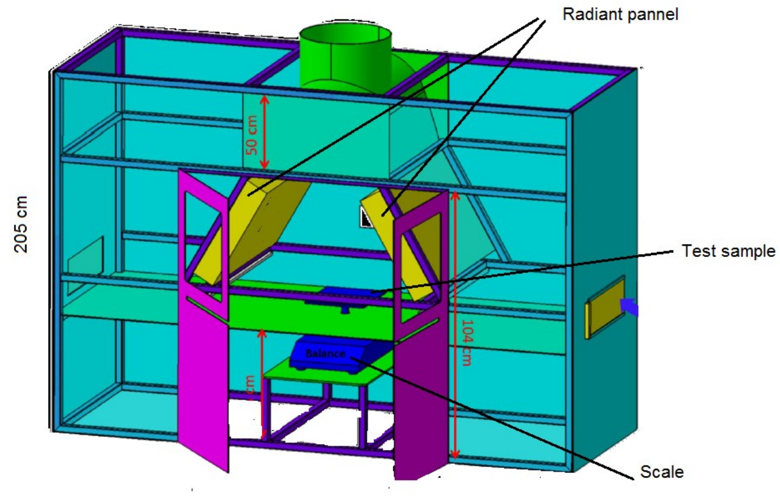

Figure 12. Rapaces 1.2 sketch

Figure 13. View of horizontal and vertical configuration

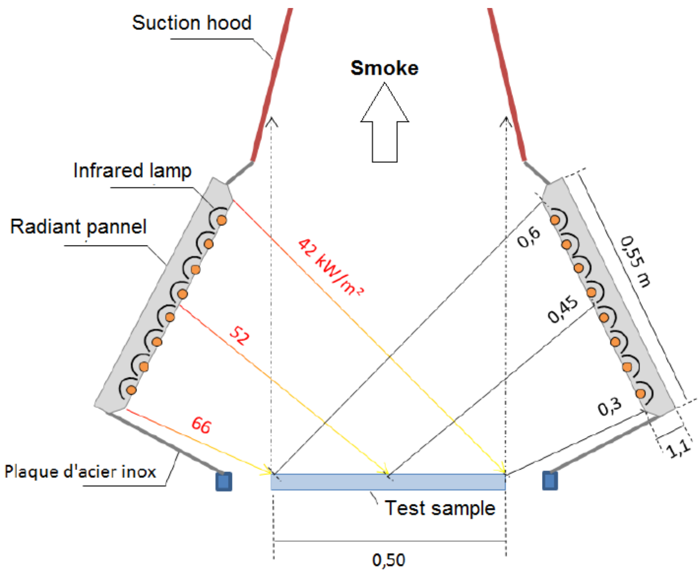

Figure 14. Sketch of incident heat flux

One of the first tests was to determine heat flux received by the target (here the incident heat flux meter) as a function of the relative intensity of the radiant panel at a given point (here the middle of the combustion chamber). Figure 15 shows an almost linear relationship between the heat flux received by the target and the relative intensity of the radiant panel.

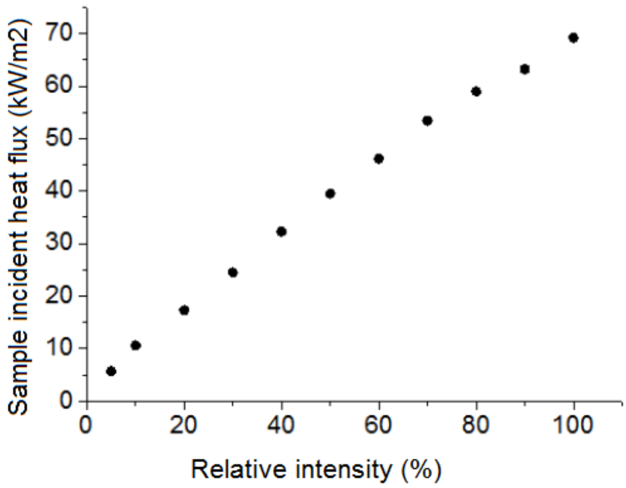

Figure 15. Heat flux received by the target as a function of the relative intensity percentage of the radiant panel (flux meter in the middle of the combustion chamber)

A map of the heat flux was carried out over the whole surface of sample area (surface of 68 cm by 90 cm). The results (Figure 16) show a distribution of the heat flux received by the target relatively homogeneous over the entire surface of the combustion chamber. For a relative intensity of the radiant panel of 40%, the heat flux received by the target is between 25.5 and 33.1 kW / m².

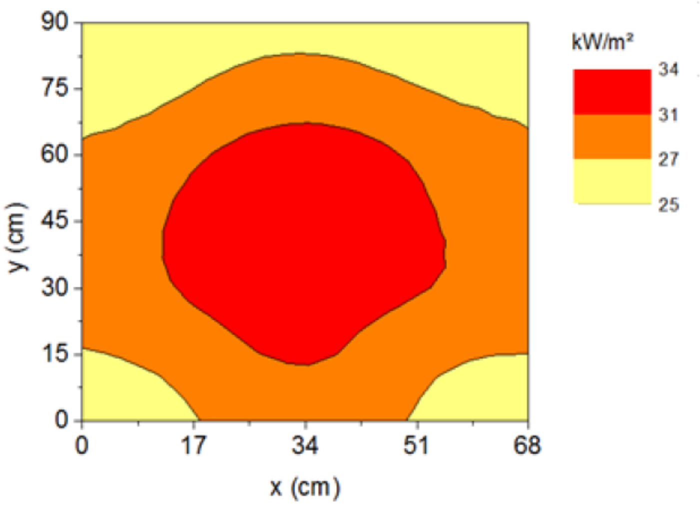

Figure 16. Mapping of the heat flux received by the target for a RAPACES 1.2 test in horizontal orientation with relative power intensity equal to 40%.

3.3. Comparison of RAPACES 1.1 and RAPACES 1.2

Tests were performed with PMMA to compare results obtained by RAPACES 1.1, RAPACES 1.2 and by calorimetric cone. Two different thicknesses of PMMA were burnt (2 mm and 4 mm thickness). Time of ignition was measured and compared. Results are very consistent (Table 1)

Table 1. Comparison of calorimetric cone, RAPACES 1.1 and RAPACES 1.2

	Time of ignition (s)				
Device	Calorimetric cone	Rapaces 1.1		Rapaces 1.2	
Thickness	4 mm	2 mm	4 mm	2 mm	4 mm
Sample configuration	Horizontal	Vertical	Vertical	Horizontal	Horizontal
35 kW/m^2	47	26	51	28	43
50 kW/m^2	24	18	25	19	24
70 kW/m^2	12	12	12	12	12

3.4. Sensors and monitoring devices related to RAPACES 1.1 and 1.2

3.4.1. Thermal camera

The institute for risk science owns a FLIR SC4000. This high-speed, high-resolution science grade camera provides Gigabit Ethernet, Camera Link and USB interfaces for maximum flexibility and performance. It also features simultaneous digital and analog outputs, and is available in multiple lens configurations. This camera allows fast frame rates, plus adjustable and triggered integration times, in order to capture fast moving objects and those with rapidly changing temperatures. A temperature measurement without contact with the sample is obtained with the camera. More details about the camera are given in part 6.

3.4.2. Temperature sensors

Thermocouples are positioned on the sample, to determine its surface temperature, and at different places in the test chamber to control the temperature of the smoke. Thermocouples are of type K with measurements until 1200 °C (± 0.5 °C).

3.4.3. Pressure sensors

A diaphragm is positioned inside the extraction pipe (diameter: 120 mm). This diaphragm has an orifice of 600 mm of diameter. Two pressure sensors are positioned before and after this diaphragm to measure the pressure difference. Thanks to this pressure difference, the volume flow rate is determined.

3.4.4. Heat flux meters

The purpose of radiative flux meters is to detect IR radiation received by the sample. Flux meters used are CAPTEC brand radiative flux meters with a surface of 50 mm x 50 mm. These heat flux-meters are regulated in temperature thanks to a water internal flow.

3.4.5. Weighing scale

A KERN weighing scale (0-20 kg ± 0.05 g) is used to continuously monitor the sample mass loss as a function of time (every 0.1 seconds).

3.4.6. Gas analyzer

A SERVOMEX 4100 series gas analyzer quantifies the concentrations of O_2, CO_2 and CO during the combustion of the material. These devices allow us to determine the HRR (Heat Release Rate) of the material.

3.5. Experimental protocol

The sample is positioned inside the sample holder. This sample holder is positioned on the weighing scale to measure the weight loss continuously. The experimental protocol is as follow.

- A shutter is positioned between the test chamber (containing the sample) and the thermal flux concentrator. The IR lamps are turned-on for preheating (2 minutes). After two minutes, the thermal flux obtained is homogeneous.
- The shutter is remoted, the data acquisition is launched: the test begins.
- The ignition of the sample is caused by the use of an ignitor.
- When the extinction is observed, the IR lamps are turned off: or the test if finished or an incandescent combustion is observed.

4. Field tests capacity

The Physics of Phenomena research team has a long experience on field tests. Figure 17 shows some examples of field tests where the team was involved.

BAM (Berlin)

CEA (Gramat)

GL ND (Spadeadam)

Firemen facility (Ales)

CNPP (Vernon)

Camp des Garrigues (Nîmes)

ARCELOR MITTAL facility (Gandrange)

Figure 17. Experimental tests sites

Most of the time the setup, control and command, data acquisition have to be set up on site. In some cases, the field is a barren area and everything has to be set up in place to perform the tests. To help working in good conditions on a barren area, a trailer was bought in 2013 and modified to become a monitoring zone for tests.

Figure 18. The trailer

Table 2. List of equipment dedicated to field tests

Description	Quantity	Specifications
Power generator	1	3 kW
Trailer	1	4 people
Weather station	2	Leader Ultrasonic 3D
Cameras	3	Panasonic

5. Sensors and monitoring devices

This section describes the sensors and monitoring devices (model, type, specifications) and data logging capacities (measured variable, data acquisition rate, precision, etc.) available at ARMINES/IMT Mines Alès.

Quantity	Model	Type	Measured variables
10	Heat flux sensors	Captec	Radiant heat flux
10	Heat flux sensors	Captec	Total heat flux
10	Cooled heat flux sensors	Captec	Radiant heat flux
2	IR pyrometer	Raytek	Emitted heat flux
1	IR camera SC4000	FLIR	IR imaging
10	Data acquisition	NI 9174	Analogic signal
12	Thermocouple module	NI 9205	Temperature
6	Voltage module	NI 9213	Voltage (heat flux)
100	K Thermocouples (1.5 mm)	TCSA	Temperature
30	K Thermocouples (1 mm)	TCSA	Temperature
20	K Thermocouples (0.5 mm)	TCSA	Temperature

6. Description of thermal camera

The characteristics of the SC4000 camera are summarized in the Table 3.

Table 3. Characteristics

Characteristics	Data
Model	FLIR SC4000
Resolution (pixels)	320 x 256
Frequency (Hz)	< 420
Wavelength Range (µm)	3-5
Temperature (°C)	< 2000
IR lens (mm)	13 or 100

Table 4. Frame rate as a function of resolution

Resolution (pixels)	Acquisition speed (Hz)
230x256	432.6
256x256	504.6
256x128	1001.4
128x128	1502
128x64	2957.9
128x32	5739.2
128x16	10831.9
128x8	19470.4
128x4	32383.4

Table 5. Other characteristics

	SC4000 HS
Detector Specifications	
Detector	Indium Antimonide (InSb)
Spectral Range	3.0 - 5.0 µm
Broadband Option	1.5 - 5.0 µm
Resolution	320 (H) x 256 (V) / 640 x 512
Pixel Pitch	30 x 30 / 25 x 25 µm
Electronics & Data Rate	
Integration Type	Snapshot
Integration Time (Electronic Shutter Speed)	9 µS to full frame time
Read-out Modes	Asynchronous Integrate while read Asynchronous Integrate then read
Dynamic Range	14 bits
Data Rate	50 MHz
Full Frame Rate	Programmable 1Hz - 420Hz / 1 Hz - 125 Hz
Subwindowing	Yes — user defined
Minimum Window Size	
Superframing	Yes — up to 4 presets
Preset Sequencing	Yes — up to 4 presets
Performance Specifications	
NEI / NETD	< 25mK (18mK typical)
Well Capacity	18 M electrons / 11 M electrons
Operability	>99.5% >99.8% typical
Camera Specifications	
Sensor Assembly f/#	f/2.5 standard, f/4.1 optional
Sensor Cooling	Stirling closed cycle cooler; optional Liquid Nitrogen (LN_2)
Lens Mount	Twist-lock Bayonet
Power	24 VDC
Advanced Communication and Data Transfer	
Command and Control	
Data	

Lenses - Optionally Available		
InSb Camera Lenses - (3.0 - 5.0 microns)		
Lens Focal Length	**320 x 256 Resolution**	**640 x 512 Resolution**
13 mm	40.5° x 32.9° FoV	63.2° x 52.4° FoV
25 mm	21.7 x 17.5° FoV	35.5° x 28.7° FoV
50 mm	11.0° x 8.8° FoV	18.2° x 14.6° FoV
100 mm	5.5° x 4.4° FoV	9.1° x 7.3° FoV
Dual Field of View 50/250 mmElectronics & Data Rate	50 mm (11° x 8° FoV) 250 mm (2.2° x 1.8° FoV)	50 mm (18.2° x 14.6° FoV) 250 mm (3.7° x 2.9° FoV)
Triple Field of View 60/180/500 mm	60 mm (9.1° x 7.3° FoV 180 mm (3.1° x 2.4° FoV) 500 mm (1.1° x 0.9° FoV)	60 mm (15.2° x 12.2° FoV 180 mm (5.1° x 4.1° FoV) 500 mm (1.8° x 1.5° FoV)
Microscope	1x 2.5x 4x	1x 2.5x 4x