Field campaign characterization of incense and candle emissions in indoor environment

M. Nicolas, D. Buiron, E. Quivet, Alexandre Albinet, Guillaume Karr, François Maupetit

Field campaign characterization of incense and candle emissions in indoor environments (EBENE project)

Mélanie NICOLAS[1,*], Daphné BUIRON[2], Etienne QUIVET[2], Alexandre ALBINET[3], Guillaume KARR[3], François MAUPETIT[1]

[1] CSTB (Centre Scientifique et Technique du Bâtiment), Saint-Martin d'Hères, France
[2] Aix-Marseille Université, CNRS, Laboratoire de Chimie de l'Environnement, UMR 7376, 13331 Marseille, France
[3] INERIS (Institut National de l'Environnement industriel et des RISques), Parc technologique Alata, BP 2, 60550 Verneuil-en-Halatte, France

[*] *Corresponding email: melanie.nicolas@cstb.fr*

SUMMARY
Burning incense and scented candles indoors has been shown as a punctual but significant source of volatile and particulate compounds. The purpose of this paper is to present the results of testing emissions from incense and candles burning under realistic conditions in the CSTB experimental house. Particular effort was given to the use of adequate on-line and off-line measurement techniques to precisely describe volatile and particulate compounds emitted during combustions of those products. This information is particularly relevant for the implementation of the labelling of emissions from candles and incense and for risk assessment studies related to the use of those products.

PRACTICAL IMPLICATIONS
Burning incense and scented candles in indoor environments can expose consumer to high levels of gaseous and particulates compounds not only during combustion but also during the following hours depending on the efficiency of the ventilation system to remove generated pollution. Information of consumers on emissions and on good practices is needed to reduce their exposure.

KEYWORDS
Candles, incense burning, VOCs, formaldehyde, PAHs, PTR-ToF-MS, particles

1 INTRODUCTION
Burning incense and scented candles indoors has been shown as a punctual but significant source of volatile and particulate compounds (Maupetit and Squinazi, 2009; Ji et al. 2010; Manoukian et al. 2013; Nicolas and Maupetit, 2015). Source control actions have been implemented in France through the mandatory labelling of volatile emissions from building products and paints since 2013. Similar labelling of emissions from furniture is expected for 2020. The French Action Plan for Indoor Air Quality (IAQ) presented in 2013 stated that labelling of emissions from air fresheners (including incense and scented candles) should also be implemented. Standardization work is in progress at CEN TC421 "Emission safety of combustible air fresheners" and a draft standard for the determination of emissions from scented candles and incense burning is available (CEN, 2015).

The purpose of this paper is to present the results of testing emissions from incense and candles burning under realistic conditions in the CSTB experimental house. Particular effort was given to the use of adequate on-line and off-line measurement techniques to precisely describe volatile and particulate compounds emitted during combustions of those products.

This information is particularly relevant for the implementation of the labelling of emissions from candles and incense and for risk assessment studies related to the use of those products (Karr et al. 2016).

2 MATERIALS/METHODS

A panel of 18 products has been selected for this study from different manufacturers and sellers. They do not intend to be statistically representative of the French market but they are available and can be used by consumers. The selected products include 9 scented candles and 9 incense products (sticks and cones).

Experiments have been conducted in a specific room of the CSTB experimental house dedicated to indoor air research (MARIA) already used for previous studies on emissions from air fresheners (Maupetit and Squinazi, 2009; Ji et al. 2010; Manoukian et al. 2013; Nicolas and Maupetit, 2015). The 32 m^3 room is empty and indoor surfaces are raw concrete on the floor, painted gypsum on the walls and painted concrete on the ceiling. The principle of testing is to use selected products under realistic conditions. For each experiment, one product is burnt in the centre of the test room. The air exchange rate during experiments has been maintained around 0.65 h^{-1} using mechanical extraction. Temperature and relative humidity were monitored continuously during all experiments. After checking the background level of pollutants in the room, particulates and volatile gaseous compounds have been measured and monitored during the combustion phase of the product, and for at least the following three hours. The impact of ignition mode (i.e. use of a lighter vs matches) has been studied for both incense and candle. The sampling strategy was the following:

- Sample 1: Combustion of the tested product (maximum time = 1 hour)
- Sample 2: Post combustion 1 (duration = 1 hour)
- Sample 3: Post combustion 2 (duration = 1 hour)
- Sample 4: Post combustion 3 (duration = 1 hour)

For incense, duration of the first sampling is adjusted to the combustion of the tested products. For scented candles, the first sampling is limited to one hour and the candle is blown down.

Different measurement techniques have been implemented during this campaign to combine volatile gaseous and particulate off-line measurements (sampling of VOCs, aldehydes, and PAHs on specific adsorbents) and on-line measurements (PTR-ToF-MS, HR-ToF-AMS, SMPS, TEOM, aethalometer used continuously). Monitoring of nitrogen oxides and ozone has also been performed.

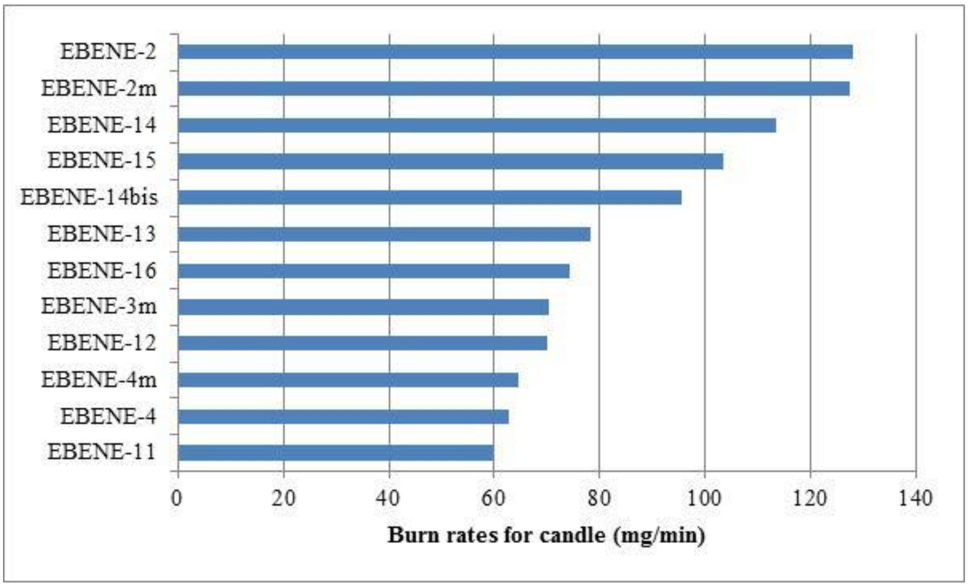
Volatile organic compounds (VOCs) were sampled and analyzed according to ISO 16000-6 (2011). Samples were collected on Tenax TA sorbent tubes (Perkin Elmer) at 80 mL/min air flow rate and analyzed by thermal desorption (ATD Turbomatrix 350, Perkin Elmer) and gas chromatography (CG) with a flame ionization detector (FID) (Perkin Elmer Autosysteme XL) for quantification and a mass spectrometer (MS) (Perkin Elmer Turbomass) for identification and quantification. Carbonyl compounds (including formaldehyde, acetaldehyde, acrolein) were sampled and analyzed according to ISO 16000-3 (2011). Samples were collected on DNPH coated cartridges (Waters) at 600 mL/min air flow rate and analyzed using HPLC-UV (Alliance, Waters) after liquid extraction with 5 mL of acetonitrile.

Emission data have been obtained for carbonyl compounds, including formaldehyde, acetaldehyde, acrolein; volatile organic compounds, including benzene, toluene; PAHs and their nitrated and oxygenated derivatives; black carbon; and particles (number, mass, size, and composition). These data have also been used in another task of the EBENE project dedicated to health risks assessment (Karr et al. 2016).

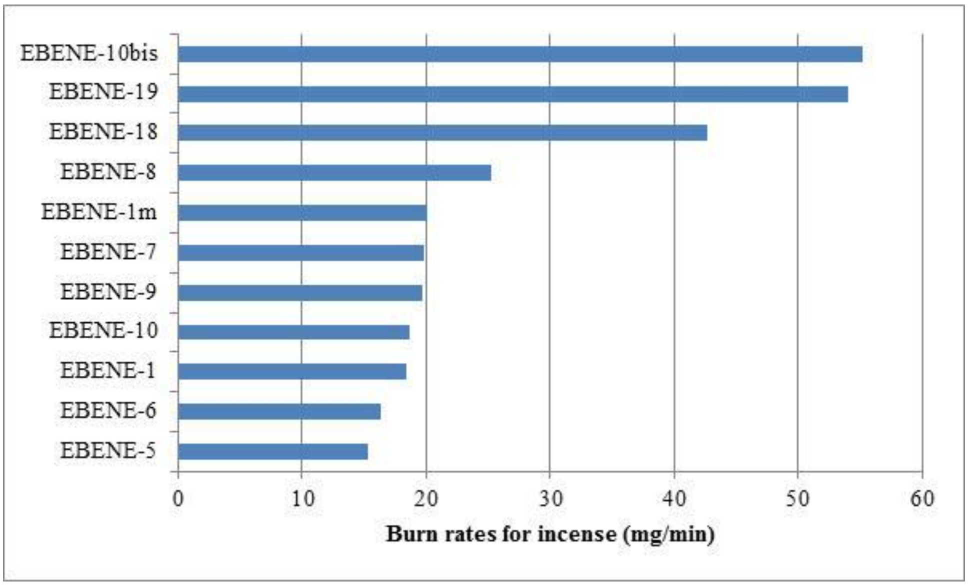
3 RESULTS

Burn rates

The burn rates (i.e., ratio between the mass burned and the time of combustion, in mg/min) were calculated for each experiments. Results are presented on Figure 1 for scented candles (a) and incense (b). Values obtained for scented candles are higher than for incense: burn rates ranged between 60 to 130 mg/min for scented candle while burn rates are still below 60 mg/min for incense. Results obtained for replicates are similar, except for EBENE-10. Heterogeneity in incense preparation present in the same batch may explain this result. Further laboratory experiments will be performed to assess the dispersion of incense weight within the same batch (Garnier et al., 2016).



a)



b)

Figure 1. Burn rates for candles (a) incense (b), in mg/min (m: test with matches, bis: replicate)

Emissions from scented candles and incense products

Results of measured concentrations of target compounds in the CSTB experimental house (MARIA) for the 9 scented candles and 9 incense products are summarized in Table 1 for benzene, toluene, formaldehyde, acetaldehyde and NOx. Ozone concentrations were not significant during the experiments. For PAHs, results for incense products are presented in Table 2. For the scented candles, concentration of benzo(a)pyrène, benzo(a)anthracène and dibenzo(ah)anthracène were less than 0.3 ng/m^3.

Table 1. Emission of scented candles and incense products measured in the experimental house (*measurement with PTR-ToF-MS analysis)

compounds	sampling	Scented candles		Incense	
		average	stand. dev.	average	stand. dev.
benzene	combustion	0.9	0.6	55.6	68.4
	post- combustion 0-1h	0.8	0.6	71.3	92.5
	post- combustion 1h-2h	0.8	0.4	33.3	41.1
	post- combustion 2h-3h	0.6	0.5	20.1	24.3
	hour average maximum*	0.3	0.2	92.4	114.2
toluene	combustion	3.0	2.7	26.2	18.3
	post- combustion 0-1h	2.1	2.2	27.6	21.4
	post- combustion 1h-2h	1.9	2.6	15.6	12.1
	post- combustion 2h-3h	1.3	0.3	26.0	36.4
	hour average maximum*	1.2	1.0	28.0	22.5
formaldehyde	combustion	2.3	1.7	33.1	10.6
	post- combustion 0-1h	5.8	3.8	25.0	7.6
	post- combustion 1h-2h	3.8	2.7	9.2	3.1
	post- combustion 2h-3h	5.7	4.2	7.3	4.2
	hour average maximum*	11.7	11.2	51.2	22.2
acetaldehyde	combustion	0.8	0.7	38.6	34.7
	post- combustion 0-1h	1.8	2.2	49.6	39.8
	post- combustion 1h-2h	1.5	1.0	24.5	18.3
	post- combustion 2h-3h	1.2	0.6	14.1	10.4
	hour average maximum*	28.4	40.7	78.2	55.9
NOx	combustion	55.7	20.8	11.4	7.9
	post- combustion 0-1h	73.4	28.9	13.7	8.1
	post- combustion 1h-2h	20.6	18.6	5.2	10.5
	post- combustion 2h-3h	4.4	6.1	2.0	6.2
	hour average maximum*	89.4	30.2	19.7	10.1

The average of benzene concentration measured in the experimental house is lower than 1 µg/m^3 for all the scented candles tested, values ranged between 0.1 to 2.0 µg/m^3. Concentrations of toluene seem to be slightly higher. For carbonyl compounds, formaldehyde and acetaldehyde are the target substance observed.

With regard to incense products, as shown in previous studies, benzene, formaldehyde and acetaldehyde are the volatile compound emitted at the highest concentration levels and emissions are at their maximum during combustion and just after combustion (post combustion 1 sample and for few tested candles, combustion 2 sample) (Maupetit and Squinazi, 2009; Manoukian et al. 2013). Measured concentrations in the experimental house resulting from burning incense sticks actually available on the market in 2014 were higher than measured in the same conditions by Maupetit and Squinazi (2009) because the aim of this previous study was the reduction of emissions from incense products from the same producer.

Table 2. Concentration of PAHs (in ng/m^3) measured for incense in the experimental house (m: with matches; no indication: with lighter)

Products	benzo(a)pyrène	benzo(a)anthracène	bibenzo(ah)anthracène
EBENE-1m	1.2	0.4	0.0
EBENE-1	1.0	1.2	0.0
EBENE-5	0.5	0.0	0.0
EBENE-6	1.6	1.7	0.0
EBENE-7	2.9	2.1	0.0
EBENE-8	3.8	3.9	0.1
EBENE-9	1.7	4.5	0.3
EBENE-10m	2.2	8.8	0.2
EBENE-10	1.2	2.4	0.1
EBENE-18	9.1	6.4	0.6
EBENE-19	8.1	5.9	2.0
average	3.0	3.4	0.3
standard deviation	2.9	2.8	0.6

4 DISCUSSION

Emissions of incense vs emissions of candles

Emissions of incense are very much higher than emission of scented candles. Concentrations of benzene, toluene, formaldehyde and acetaldehyde, PAHs, target compounds observed, are 10 to 100 much important for incense.

Results of particles measurement are still under validation process, especially for HR-ToF-AMS analysis.

Ignition mode

The impact of ignition mode is studied by experiments realized with the use of matches (reference of the experiment with “m”) or a lighter (all the other experiments). When matches were used, emissions of the products (scented candle or incense) were hidden by emission of the matches, especially for particles measurements.

Acroleine measurement

It’s interesting to note that acroleine were detected with PTR-ToF-MS for all the experiments involved incense products at significant concentration (average concentration: 34 µg/m^3, standard deviation: 11.4 µg/m^3, ranged between 7.6 and 47.9 µg/m^3). However, no significant value was detected for this compound after analysis of DNPH sampling.

Although sampling point for the inlet of PTR-ToF-MS and DNPH cartridge were much closed, on-line measurements were carried out directly inside the room while off-line cartridges were plugged on the controlled mechanical exhaust system located at the bottom of the door. Acroleine is a very high reactive compound that can react with surface of the system of ventilation regulation. Further investigations are in progress in the experimental house to understand this phenomenon.

Presentation of the incense

One incense products from the same producer and with the same perfume were tested in three different type of presentation: classic (EBENE-9) and large (EBENE-19) stick and cone (EBENE-10). For those products, cone and large stick combustion were associated with higher burnt mass and lower burnt time, resulting in higher burn rates. The higher burn rate of the cone and the large stick are associated with higher emissions of all target compounds.

5 CONCLUSIONS

Emissions from incense and scented candles burning under realistic conditions in the CSTB experimental house were analysed during an specific field campaign which combine on-line and off-line measurement of VOCs, aldehydes, PAHs, and particles. Many parameters were studied thanks to that field campaign and in particular the impact of the type of product use (incense or scented candle), the ignition mode, and the presentation of incense.

Concentration of VOCs, aldehydes, PAHs and particles were determined for different time during the use of the product (during the combustion and 3 hour after).

Results of these experiments are particularly relevant for the implementation of the labelling of emissions from candles and incense and for risk assessment studies related to the use of those products (Karr et al. 2016).

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