PRELIMINARY CHARACTERIZATION OF THE EMISSIONS FROM SCENTED TEA-LIGHT CANDLES

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Abstract

In recent years, scented candles have grown in popularity as indoor fragrance products, thus increasing the safety concern related to the air pollutants in candles emissions. Among the different types of candles, scented tea-lights are probably the most widespread, but few studies are present in literature regarding their emissions. Therefore, this preliminary study aims to characterize the emissions of several volatile and semi-volatile compounds from burning of scented tea-light candles. A laboratory-scale test chamber has been used for this purpose, as it can provide reproducible and realistic burning conditions. Emissions in terms of CO, SO_2, NOx as well as short chain aldehydes, volatile organic compounds and particulate matter have been evaluated for all candles. In addition, raw materials in terms of both waxes and wicks have been analyzed to evaluate the content of heavy metals and sulfur. As a result, all tested samples showed low emissions of CO, SO_2 and NOx. All candles emitted formaldehyde and acetaldehyde, the emission of the latter being very low. PM emissions were low and mainly dominated by ultrafine particles in the range of 0.3-0.5 μm. Analysis of the waxes and wicks revealed no traces of heavy metals and low content of sulfur.

Introduction

Both indoor and outdoor sources can affect the concentration and composition of pollutants in indoor air. There is usually more information available on emissions characteristics, such as emission factors or emission rates, of outdoor pollutants sources than of indoor ones [1]. However, the assessment and quantification of emissions from indoor sources is very important for assessing the possible human exposure to pollutants and relate the measured emission values to the regulatory guidelines. Combustion processes are among the main indoor pollutant sources, releasing gaseous pollutants and fine particles in indoor environments. In recent years there has been an increase in the use of scented candles and, consequently, of the concern about possible human health effects due to the exposure to their emissions. In fact, burning of candles can release a wide variety of chemicals, including short chain aldehyde (SCA), polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) [2,3]. Candles can also be source of ultrafine particles [4]. Tea-light candles are among the most widespread types of candles, due to their low price and high availability; however, very few studies regarding tea-lights are available in the literature and are focused on volatile organic compounds [5] and odorous volatile organic compounds [6]. Therefore, this preliminary work focused on the characterization of the emissions from scented tea-lights burning in a lab-scale test chamber. The emissions of SCA, VOCs and PM of all scented candles were measured to evaluate the emission factors, which have also been compared to the few data available in the literature. Measurements have been carried out for an unscented sample as well, to estimate the possible influence of fragrances and dyes to the emissions. In addition, the raw materials of all candles were analyzed to evaluate the concentration of heavy metals and Sulfur as well as the thermal stability. This may provide further insights regarding the relation between wax composition and pollutants emission.

Experimental setup

The selected tea-light candles are mainly composed of paraffin, molded in a cylindrical shape and surrounded by an aluminum shell. Candles have an average weight of 12 g. Selection criteria were based on providing variety of both fragrances and countries. All candles tested in the study are shown in Table 1.

Table 1. Main features of the candles investigated in the present study.

Candle	Fragrance	Color	Country
A	-	White	Poland
B	Vanilla	Brown	China
C	Jazmin	Green	Spain
D	Fruit Cake	Yellow	Poland
E	Winter Warm	Crimson	Belgium

Experimental tests were conducted in the test chamber depicted in Figure 1. The chamber is conceived to assure reproducible and realistic burning conditions and to sample the exhausts easily [7,8]. It exhibits a total volume of about 175 L. The chamber is equipped with an air sparger at the bottom to supply the air in laminar conditions; for all experiments pre-cleaned air, passed through a charcoal trap, has been used. The air flow rate was adjusted to reach realistic burning conditions. For all experiments three candles were burnt simultaneously; each candle was weighted before and after the test and the corresponding burning time was recorded.

Materials and methods

Sampling of the exhausts was carried out according, when possible, to the European Standard EN 16738:2015 [9]. Before entering the chamber, candles are weighted and burnt for 20 minutes, to ensure stable combustion. Main combustion products (CO_2, CO, NOx e SO_2) were measured with an on-line gas analyzer

(Horiba PG-250) and CO concentration was used as a marker of steady-state conditions during the experiments. In steady-state, exhausts were collected and analyzed for evaluation of SCA, VOCs and PM.

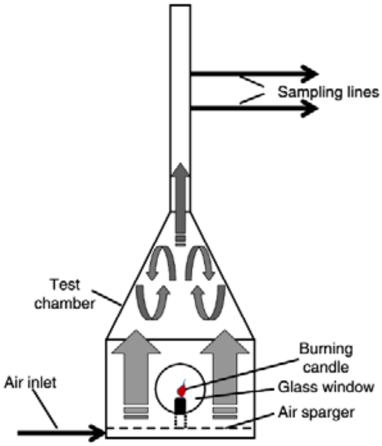

Figure 1. Schematic of the combustion chamber with arrows roughly representing air patterns [8].

Aldehydes were sampled according to the DNPH (2,4-dinitrophenylhydrazine) method: sampling of 60 min through the DNPH cartridge with a sampling flow of about 1.5 L min^{-1}; then, the cartridge was eluted with acetonitrile and analyzed through HPLC (Hypersil Gold C18 column, 5 µm, 250 mm, detector UV@360 nm). VOCs were sampled for 240 min at 50 mL min^{-1} using a charcoal cartridge (Carbotrap 349); the content was desorbed thermally and analyzed through GC/MS (Restek column Rxi-5Sil-MS, 5 µm). PM was measured using an OPC (Lighthouse model 3016-IAQ), to evaluate the time-averaged particles concentration (sampling of 30 s at 2.8 L min^{-1}) according to six dimensional classes (0.3, 0.5, 1, 2.5, 5 and 10 µm). In addition, characterization of the raw materials was carried out through a TGA/DTA (heating rate of 1 °C min^{-1} until 90 °C and 5 °C min^{-1} until 500 °C), using Nitrogen as carrier gas (flowrate of 100 NmL min^{-1}). Waxes and wicks were also mineralized to be analyzed through ICP/OES to evaluate their content of sulfur and heavy metals (especially Pb and Ni).

Results and discussion

TG analysis revealed similar behaviors for all tested candles. All candles are made up of low-melting wax, with an average melting point of 45 °C, and evidenced a good thermal stability, as shown by the TG plot of sample C in Figure 2. Elemental analysis revealed no significant amount of Pb or Ni; traces of Sulfur were found in the waxes, with values in the range of 20-50 µg g^{-1}.

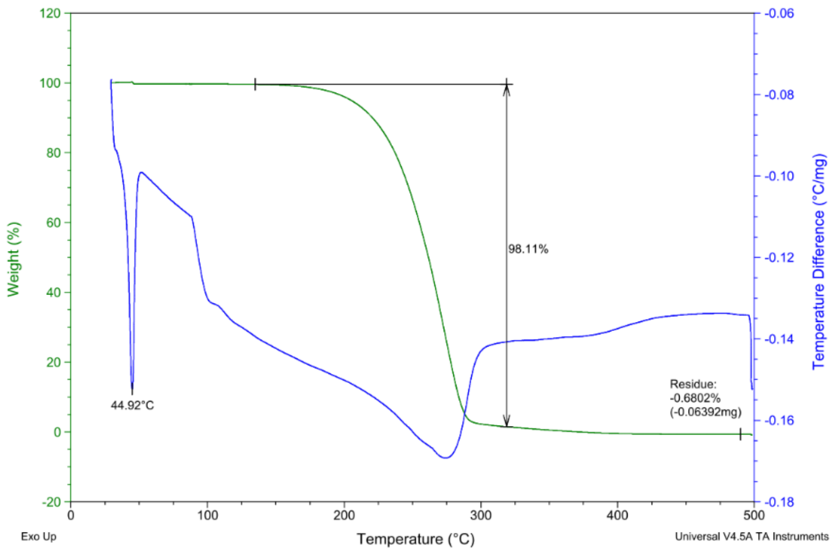

Figure 2. Results of TG analysis of sample C.

Candles were weighted before and after each test and the resulting average burning rate was compared to the burning rate of the same candle in air. Average burning rates and normalized mass loss differences with respect to the reference values are reported in Table 2. All mass loss values fall inside the ±15% region, as prescribed by the European Standard EN 16738:2015 [9].

Table 2. Average burning rate (g h^{-1}) inside the chamber and normalized mass loss difference (% by weight) between burning rate inside and outside the chamber.

Candle	Avg. Burning Rate	Norm. Mass Loss Diff.
A	2.43	+ 0.4
B	1.91	- 4.3
C	2.28	+ 2.2
D	2.92	- 1.8
E	3.10	+ 3.8

Gaseous measurements showed presence of CO, NOx and SO_2 in the exhausts. Concentration of CO ranges from 9 to 14 ppm and is similar for all samples (air exchange rate of 2 h^{-1}). NOx emissions are even lower, ranging from 2 to 5 ppm, and are closely linked to the burning rate. SO_2 emissions always fall in the range 2-3.5 ppm, independently of the burning rate. Sampling and analysis of SCA showed that formaldehyde and acetaldehyde are present in the exhausts for all samples, as shown in Table 3. Unscented candle A evidenced factors similar to the other specimens, contrarily to what was found for other types of candles [7].

Table 3. Emission factors of light aldehydes (µg g^{-1}) for all tested samples.

Candle	Formaldehyde	Acetaldehyde
A	2.56	0.41
B	3.84	0.68
C	2.97	0.86
D	6.09	1.34
E	4.33	0.62

Conversely, VOCs concentrations were always close to or below the quantification limit. Measurements with the OPC were used to compute PM emission factors, which are proposed in Table 4.

Table 4. Emission factors of PM (µg g^{-1}) for all investigated samples, according to six dimensional classes (µm).

Candle	0.3-0.5	0.5-1	1-2.5	2.5-5	5-10	> 10
A	0.42	0.16	0.11	0.12	0.01	<0.01
B	0.51	0.18	0.18	0.23	<0.01	<0.01
C	0.03	0.01	0.03	0.06	<0.01	<0.01
D	0.34	0.15	0.11	0.10	<0.01	0.01
E	0.33	0.13	0.10	0.12	<0.01	0.01

PM factors are at least one order of magnitude lower than those of formaldehyde. Again, emissions from candle A are comparable to the ones from scented samples. Ultrafine particles (0.3-0.5 µm) usually represent half of the distribution, while factors in the ranges 0.5-1, 1-2.5 and 2.5-5 µm are comparable. As an example, Figure 4 proposes the relative abundance of the different classes for candle A.

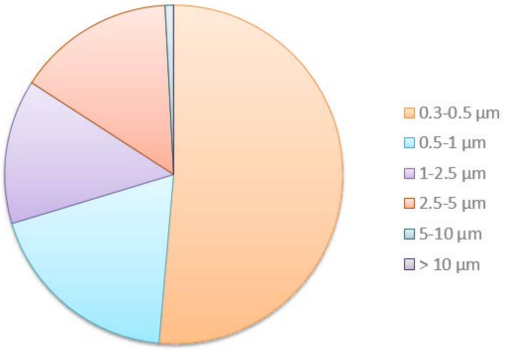

Figure 4. Graphical representation of the estimated abundance of size fractions in PM emissions for candle A.

Table 5. Comparison among emission factors (in μg g^{-1}) from different studies.

Pollutant	This study (max. value)	Uhde and Schultz [5]	Derudi et al. [7][1],[8][2]
Formaldehyde	6.09	6.5	2.91[1]
Acetaldehyde	0.86	3.0	1.12[1]
PM2.5	0.87	-	3.29[2]

The estimated emission factors have been compared to the few information available in literature regarding tea-lights [5] and to some previous works [7,8], as summarized in Table 5. Emission factors for aldehydes are comparable to the ones obtained by Uhde and Schultz [5] for a tea-light paraffin candle and to the one by Derudi et al. [7], while acetaldehyde and PM are lower of one order of magnitude.

Conclusions

Raw materials analysis showed rather homogeneous, low-melting materials, with traces of Sulfur and free of heavy metals. Measurements in the test chamber revealed that scented tea-lights can be source of several air pollutants, mainly formaldehyde and PM, especially ultrafine particles. A comparison with data available in literature showed that emissions from different type of candles can be rather different. This clearly evidences the need for simple and cheap methodologies to measure emissions from scented tea-light candles to foresee the possible exposure of people to harmful compounds in indoor environments.

References

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