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Assessment of indoor chemical pollutant emissions from scented candle burning

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Original article

Abstract

Background: Scented candles are widely used indoors for decorative and aromatherapeutic purposes, but combustion may contribute to the accumulation of gaseous pollutants and deterioration of indoor air quality.

Objective: To assess temporal changes in formaldehyde, total volatile organic compounds, carbon dioxide, carbon monoxide, and benzene during the combustion of three commercially available scented candles.

Materials and methods: Three different scented candle products were tested individually in a residential room with a floor area of 11 m^2 and an approximate volume of 25 m^3. Each candle was burned for 60 minuts in a closed room. Pollutant concentrations were monitored using a low-cost ZN-MT32 multi-parameter air-quality sensor at 0, 5, 10, 15, 30, 45, and 60 minuts. One experimental run was performed for each candle.

Results: Carbon dioxide increased for all candles. The increases after 60 minuts were 414 mg/m^3 for candle A, 493 mg/m^3 for candle B, and 326 mg/m^3 for candle C. Formaldehyde showed the maximum concentration for candle C, reaching 132 µg/m^3, while maximum concentrations for candles B and A were 55 and 24 µg/m^3, respectively. Maximum total volatile organic compounds concentrations were 332, 139, and 64 µg/m^3 for candles C, B, and A, respectively. No measurable changes in carbon oxide or benzene were observed under the experimental conditions.

Conclusions: The tested candles produced different temporal pollutant profiles. Candle C showed the highest formaldehyde and total volatile organic compounds concentrations, whereas candle B produced the largest increase in indoor carbon dioxide. The findings support the need for adequate ventilation during prolonged candle use. Because the study used a low-cost sensor and a single experimental run per product, the results should be regarded as indicative rather than as reference-grade emission measurements.

Keywords

- scented candles
- indoor air quality
- formaldehyde
- volatile organic compounds
- carbon dioxide

Authors' contributions

A – Preparation of the research project
B – Assembly of data for the research undertaken
C – Conducting of statistical analysis
D – Interpretation of results
E – Manuscript preparation
F – Literature review
G – Revising the manuscript

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Conflict of interest

None declared.

Introduction

Indoor air quality is an important environmental and public-health issue because people spend a large proportion of their time indoors. Indoor environments contain numerous potential pollution sources, including cooking appliances, heating systems, tobacco smoke, cleaning products, incense, and candles. Scented candles are widely used for decorative and aromatherapeutic purposes; however, their combustion may contribute to the release of gaseous and particulate pollutants [1].

Candle combustion is not necessarily complete and may generate carbon monoxide (CO), particulate matter (PM), volatile organic compounds (VOC), formaldehyde (HCHO), benzene (C_6H_6), acrolein (C_3H_4O), and polycyclic aromatic hydrocarbons (PAHs) [2]. The quantity and composition of emissions can depend on wax composition, fragrance additives, wick material, combustion conditions, and ventilation rate. Previous investigations have reported gaseous and particulate emissions during the burning of scented and unscented candles [3,4].

Formaldehyde is an important indoor air pollutant because of its irritant properties and established carcinogenicity. Benzene is also a carcinogenic compound associated with adverse health effects following long-term exposure. In poorly ventilated environments, combustion-related emissions may therefore contribute to increased exposure [2,3]. Carbon dioxide is a direct product of combustion and its indoor concentration can also reflect the balance between pollutant generation and ventilation. Previous studies have reported increases in indoor CO_2 during candle burning [4].

In addition to gaseous pollutants, candles can emit particulate matter and ultrafine particles [5]. These emissions may be influenced by incomplete combustion and wick behaviour [1]. The composition of scented candles and their emission profiles can therefore differ considerably between products.

The objective of the present study was to compare temporal changes in HCHO, TVOC, CO_2, CO, and benzene concentrations during the combustion of three commercially available scented candle products. The study was designed as a comparative assessment under controlled indoor conditions using a low-cost multi-parameter air-quality sensor.

Materials and methods

Tested candles

Three commercially available scented candles differing in brand, declared burning time, and fragrance composition were selected. Each product (Figure 1) was tested individually under comparable experimental conditions.

Candle A (sample A) was a Pepco Home scented candle with a declared burning time of approximately 20 hours. Candle B (sample B) was marketed as Jungle Scented Candle (ID 1184, Art. No. 27281782), manufactured and distributed by Kapimex B.V., the Netherlands, with a declared burning time of approximately 15 hours. Candle C (sample C) was a Livarno Home anti-tobacco scented candle with a declared burning time of approximately 32 hours.

Figure 1. Tested scented candles: (A) Pepco Home scented candle, (B) Jungle scented candle (Kapimex B.V.), and (C) Livarno Home anti-tobacco scented candle (photo by N. Chyc)

Experimental conditions and measurements

Before testing, all candles were stored at room temperature and remained unopened until the beginning of the experiment. The experiments were conducted in a residential room with a floor area of 11 m^2 and an approximate volume of 25 m^3. Each candle was burned individually. The room remained closed during the 60-min measurement period to minimize external air exchange and to allow assessment of pollutant accumulation associated with combustion. The burning rates of candles A, B, and C were: 4.6 g/h, 3.6 g/h and 3.1 g/h respectively.

The average indoor air temperature during the experiments was 27 ± 2 °C and the average relative humidity was 62 ± 4%. Environmental conditions were monitored throughout the study to ensure comparable conditions between experiments. The operator was not present in the room during measurements. A webcam system was used for remote observation of the measuring device.

Concentrations of HCHO, TVOC, CO_2, CO, and C_6H_6 were monitored using a ZN-MT32 low-cost multi-pa-

rameter air-quality sensor (Figure 2). Measurements were recorded at seven predefined time points: 0, 5, 10, 15, 30, 45, and 60 min after ignition. The instrument was positioned at a fixed location within the room for each experiment. The technical specifications of the device were taken from the available device manual [6].

Figure 2. Tested ZN-MT32 low-cost air-quality device

Measurement limitations

The ZN-MT32 is a low-cost sensing device and was not validated against reference analytical instruments before the experiments. Consequently, the reported concentrations should be regarded as approximate and indicative. The principal purpose of the measurements was comparative assessment of temporal trends and relative differences between the tested products rather than reference-grade quantification of emission rates. According to the manufacturer, the device measures CO_2 within the range of 400–5000 ppm, CO within 0-999 ppm, HCHO within 0–1.999 mg/m^3, TVOC within 0–9.999 mg/m^3, and benzene within 0–1.999 µg/m^3. The sensor resolutions reported by the manufacturer are 1 ppm for CO_2, 0.01 mg/m^3 for HCHO, and 0.01 mg/m^3 for TVOC [6]. Detailed information regarding measurement accuracy, detection limits, calibration procedures, and cross-sensitivity of the gas sensors is not provided in the available manufacturer documentation. Although the measurements were performed using a low-cost multi-parameter air-quality sensor, previous studies have demonstrated that appropriately selected and calibrated low-cost sensors can provide satisfactory agreement with reference-grade instruments for several indoor air-quality parameters. Their relatively low cost, ease of deployment, and ability to provide continuous measurements have contributed to their increasing use in environmental monitoring and comparative exposure assessments. Nevertheless, the results obtained using such devices should be interpreted with caution, as their performance may be influenced by environmental conditions, cross-sensitivities, and sensor drift [7–9].

Because only one experimental run was performed for each candle, no estimate of between-run variability could be obtained. Accordingly, the observed differences should not be interpreted as statistically generalizable differences between candle brands or product categories.

Results

Carbon dioxide

Figure 3 presents the temporal changes in indoor CO_2 concentration during the 60-minute combustion period. All three candles were associated with a gradual increase in CO_2 concentration. Initial concentrations ranged from 761 mg/m^3 for sample C to 812 mg/m^3 for sample B. After 60 minutes, concentrations reached 1206 mg/m^3, 1305 mg/m^3, and 1087 mg/m^3 for samples A, B, and C, respectively (Figure 3).

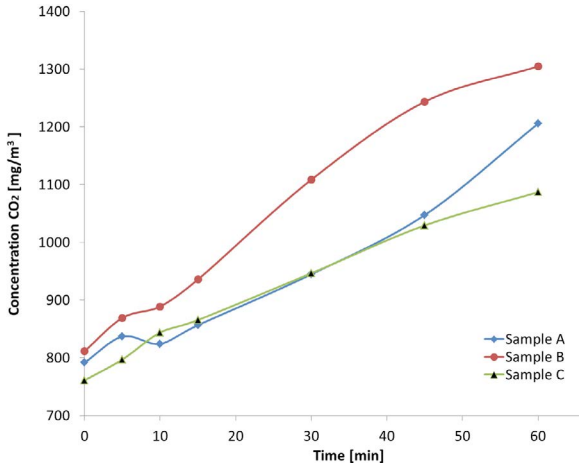

Figure 3. Changes in indoor carbon dioxide (CO_2) concentration during the 60-minute combustion of the tested scented candles (samples A–C)

The corresponding increases were 414 mg/m^3 for sample A, 493 mg/m^3 for sample B, and 326 mg/m^3 for sample C. Sample B therefore produced the largest increase in indoor CO_2 concentration under the experimental conditions, whereas sample C produced the smallest increase. During the first 15 minutes, the temporal patterns were relatively similar. After approximately 30 minutes, the increase for sample B became more pronounced.

Formaldehyde

HCHO concentrations showed greater differences between the tested products than CO_2 concentrations (Figure 4). Initial HCHO concentrations ranged from 13 to 15 µg/m^3. Sample C showed the largest increase, from 15 µg/m^3 initially to 89 µg/m^3 after 5 minutes and 131 µg/m^3 after 15 minutes. The maximum reported value was approximately 132 µg/m^3.

For sample B, HCHO increased from 13 µg/m^3 to 55 µg/m^3 after 5 minutes and remained elevated at 53 µg/m^3 after 10 minutes, followed by a decline to 3 µg/m^3 at 60 minutes. Sample A showed lower and comparatively stable concentrations, ranging from 9 to 24 µg/m^3. At the end of the experiment, HCHO concentrations were 24, 3, and 19 µg/m^3 for samples A, B, and C, respectively (Figure 4).

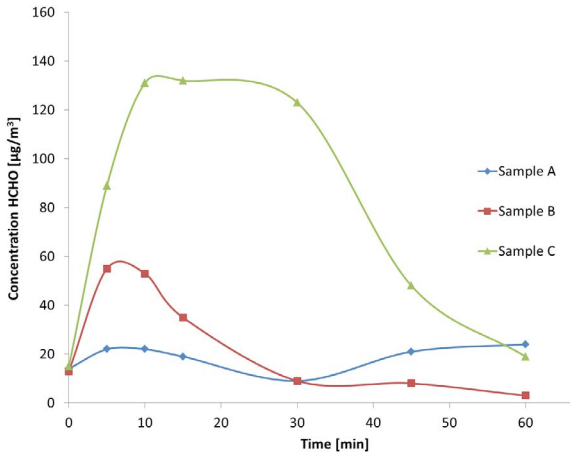

Figure 4. Changes in formaldehyde (HCHO) concentration during the 60-minute combustion of the tested scented candles (samples A–C)

Total volatile organic compounds

TVOC concentrations increased after ignition, with substantial differences in magnitude and duration between products (Figure 5). For sample C, TVOC increased from 22 µg/m^3 initially to 226 µg/m^3 after 5 minutes and reached a maximum of 332 µg/m^3 after 15 minutes. Concentrations remained above 300 µg/m^3 during the first 30 minutes and subsequently declined, although they remained above the initial value until the end of the experiment.

For sample B, TVOC increased from 67 µg/m^3 to 139 µg/m^3 within the first 5 minutes and remained similar after 10 minutes (137 µg/m^3). The concentration then decreased to 7 µg/m^3 after 60 minutes. Sample A showed the lowest and most stable TVOC concentrations, ranging from 32 to 64 µg/m^3, with a maximum of 64 µg/m^3 after 5 minutes.

The maximum TVOC concentrations recorded for samples A, B, and C were 64, 139, and 332 µg/m^3, respectively (Figure 5). Thus, sample C exhibited the highest measured TVOC concentration under the experimental conditions.

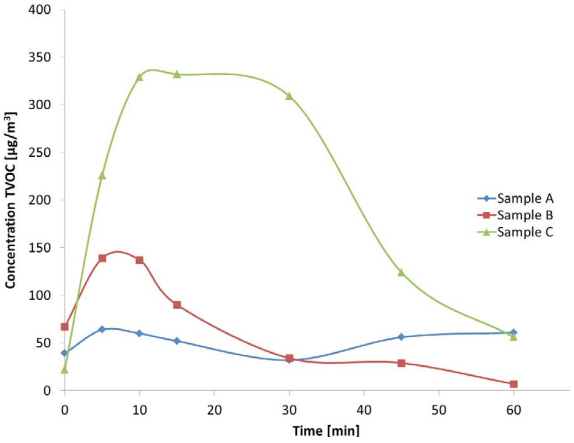

Figure 5. Changes in total volatile organic compound (TVOC) concentration during the 60-minute combustion of the tested scented candles (samples A–C)

Carbon monoxide and benzene

No measurable changes in CO or C_6H_6 concentrations were observed during the 60-minute experiments. The recorded values remained stable throughout the measurement period for all three candles. Under the applied experimental conditions, no detectable increase in these two parameters was therefore identified.

Discussion

The measurements demonstrated that the three tested scented candles had different temporal pollutant profiles. The most pronounced differences were observed for HCHO and TVOC, whereas CO_2 increased for all three products. This pattern is consistent with the general observation that candle emissions depend on product composition and combustion conditions [1].

Sample C produced the highest measured HCHO and TVOC concentrations. The rapid increase in both parameters during the initial stage of combustion suggests that the early combustion period was particularly important for pollutant accumulation in the closed test room. The subsequent decrease in some measurements may reflect changes in combustion conditions or de-

pletion of readily volatilized compounds; however, the present experimental design does not allow the specific mechanism to be established.

Sample B produced the largest increase in indoor CO_2 concentration. It is important to distinguish this finding from a direct measurement of concentration rate. The present experiment measured concentration changes in a closed room rather than mass concentration rates. Therefore, the results support the conclusion that sample B was associated with the largest increase in indoor CO_2 concentration under the tested conditions, but they do not establish that it generated the greatest mass of CO_2.

The correlation between HCHO and TVOC within individual candle experiments should also be interpreted cautiously. These results describe the similarity of temporal patterns within the individual experimental runs; because the observations are serial measurements from single runs, they should not be interpreted as evidence of a statistically generalizable relationship across candle products or independent experiments.

The absence of detectable changes in CO and benzene in this experiment should not be interpreted as proof that these pollutants cannot be emitted by scented candles. Rather, under the particular room volume, combustion conditions, monitoring period, and sensitivity of the low-cost sensor used in this study, no measurable increase was observed.

The main limitations are the small number of products, the absence of independent experimental replication, the use of a low-cost sensor without prior validation against reference analytical methods, and the use of a closed room that does not represent all real-world ventilation conditions. Future studies should include a larger number of products, repeated experiments, controlled ventilation rates, and reference-grade analytical methods to improve the reliability of pollutants quantification and exposure assessment.

Conclusions

Combustion of the three tested scented candles was associated with increases in selected indoor air-pollutant concentrations, with substantial differences between products. CO_2 increased for all candles, with the largest increase observed for sample B (493 mg/m^3). Sample C showed the highest measured HCHO concentration (approximately 132 µg/m^3) and the highest TVOC concentration (332 µg/m^3). No measurable increases in CO or benzene were observed during the experiments.

The results indicate that different scented candle products can produce distinct temporal pollutant profiles. The findings are indicative rather than reference-grade because each product was tested only once and the measuring device was not validated against reference analytical instrumentation.

Data availability

The data underlying the results are available from the corresponding author upon reasonable request.

Use of AI tools

The authors declared that during the process of creating the publication they used AI tools (Copilot M365) for the following purposes: text translation, title translation, linguistic and stylistic correction.

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