Volatile Emissions of Cigar Smoke and Their Predicted Impact on Indoor Air Quality

Hongfei Zhang, Mingqing Zhang*

School of Environment and Spatial Informatics, China University of Mining & Technology, Xuzhou 221116, China

Abstract: This study characterized emissions from cigars. This study adhered to the smoking test guidelines established by the International Organization for Standardization, and experimental tests were conducted on cigars under controlled conditions. The focus of these tests was the analysis of 20 volatile organic compounds (VOCs) in mainstream smoke. The results obtained demonstrate that cigar smoke contains not only aldehydes and a variety of VOCs, but also aromatic compounds (e.g. phenols) and a range of known or potentially harmful substances. In comparison with conventional cigarettes, cigars generally release levels of VOCs that are 1 to 2 orders of magnitude higher. Furthermore, the study investigated the potential impact of cigars on indoor concentrations of formaldehyde and other pollutants commonly encountered in domestic and public environments. This comprehensive data set provides a valuable reference point for evaluating public health risks and establishing indoor air quality standards.

1 Introduction

As China's economic stature advances and the standard of living among its populace elevates, the utilization of cigar commodities emerges as a burgeoning trend. According to data, from 2013 to 2020, the nationwide output and sales figures for cigar cigarettes in China skyrocketed from 432 million units to 5.45 billion units, marking an astounding surge of 1,261.5% [1]. Furthermore, during the period spanning 2019 to 2021, the cultivation expanse of China's cigar tobacco sector swelled from 281.4 hectares to 877.9 hectares, with the associated distribution quantities leaping from 363.7 tons to 1564.57 tons [2,3].

This study focuses on the analysis of the chemical constituents released by the combustion of cigars, particularly the VOCs in mainstream smoke, and uses advanced analytical techniques to accurately quantify them. The study covered a variety of organic compounds such as aldehydes, ketones, and aromatic hydrocarbons, and conducted a comprehensive comparative analysis with traditional cigarettes, including total VOCs and specific compound types and concentrations [4,5]. The effect of cigar emissions on indoor VOC concentrations was comprehensively analysed by simulating different use scenarios, and the potential impact on users' health and indoor environmental quality was discussed. The results showed that cigar emissions can cause health risks, such as respiratory irritation and allergic reactions, and degrade indoor air quality, affecting the comfort and health of occupants.

2 Materials and methods

2.1 Cigars

In this experiment, 6 different cigars were used in this experiment, the types of which are shown in Table 1.

Table 1. List of cigar samples

No.	Branding
1	Great Wall (Victory)
2	Great Wall (Range Rover 1)
3	Great Wall (Legend 3)
4	Mount Taishan (Peak 6)
5	Yellow Crane Tower (Snow Dream No. 5)
6	Crown (10 whole leaf rolls)

2.2 Chemicals and reference compounds

In the present study, a variety of chemical standards, including acrolein, acetic acid, triglyceride, acetyl alcohol, nicotine, diacetyl (especially 2,3-butanedione), isoprene, acrylonitrile, N-methylformamide, o-p-m-3 cresol isomers, benzene, phenol, etc., were successfully prepared by using the synthesis scheme provided by Sigma-Aldrich Company. The standard mixture of DNPH derivatives supplied by Sigma-Aldrich Company was utilised, as it is a highly effective tool for the

Contact: hfzhang1983@126.com and zmqcumt@163.com

analysis and determination of carbonyl compounds, including formaldehyde, acetaldehyde, and acrolein. In the experiment, carbonyl-free acetonitrile and GC-grade methanol supplied by Honeywell were selected as solvents, both of which can be applied directly without additional pretreatment steps. In addition, Milli-Q water, characterised by a resistivity of more than 18 MΩ·cm, was employed in the preparation of the solution with the requisite concentration, thereby ensuring the accuracy and reliability of the experimental analysis results.

2.3 Methods

The smoking process of cigars was meticulously managed in accordance with ISO specifications. Each throughput was set at 35 ml, with a duration of 2 seconds (achieving a throughput rate of 1650 cm^3 min^{-1}) and a 40-second interval. During the process, we successfully obtained samples of mainstream emissions from cigars. Concurrently, blank samples were collected prior to cigar use, enabling the determination of background concentrations of volatile carbonyl compounds and volatile organic compounds. In the present study, a 2,4-dinitrohydrazide (DNPH)-coated filter was utilised for the direct capture of volatile carbonyl groups from mainstream emissions, with the objective of minimising analyte loss during collection. In order to guarantee the integrity of the samples, new sampling equipment is substituted following each smoking session. Concurrently, the CX-572 adsorption tube (courtesy of Supelco Analytical) was employed to collect volatile organic compounds (VOCs) in the mainstream, thereby providing substantial scientific substantiation for the subsequent accurate analysis.

2.4 Chemical Analysis

Carbonyl Analysis in Mainstream Emissions. In the experimental phase, 25 ml of carbonyl-free acetonitrile was used to extract mainstream emissions trapped on DNPH-coated filters. We then analyzed the extracts using high-performance liquid chromatography (HPLC) and equipped with an Agilent Model 1200 UV detector, following the U.S. Environmental Protection Agency's (EPA) TO-11 standard operating procedure. By comparing the retention time characteristics of known dinitrohydrazone derivatives, we have successfully qualitatively identified the target analytes. For quantitative analysis, a series of standard solution concentrations were prepared and calibration curves were established to accurately determine the content of 8 carbonyl compounds.

VOCs Analysis in Mainstream Emissions. In this study, a pyrolytic inspiratory gas chromatography-mass spectrometry system (TD-GC/MS, model Agilent 6890 with 5975 detector) was utilised to conduct a comprehensive and in-depth study of the volatile components in the main and sidestream emissions. During the course of the experiment, D6-benzene was utilised as the internal standard material, in conjunction with the retention time data and mass spectrum characteristics of the standard material. This approach enabled the successful identification of the target compound with a high degree of accuracy.

2.5 Predicted Indoor Air Concentrations of Formaldehyde Emitted by Cigars

Building on previous research, this study set up two indoor environment simulation scenarios were established: one representing a domestic residential environment and the other a public bar environment. The objective of this study was to assess the extent to which non-cigar users are affected by cigar smoke emissions in these environments. The mass balance theory was utilised to calculate the concentration of formaldehyde released by cigars in the room. Formaldehyde, a known respiratory irritant, is a crucial metric for evaluating the risk of exposure:

$$E_{formaldehyde} = E_{S,\ formaldehyde} + E_{M,\ formaldehyde} * (1 - R_{formaldehyde}) \quad (1)$$

The computational model that was developed identified three key components: side-flow formaldehyde emission rate ($E_{S,\ formaldehyde}$), mainstream formaldehyde emission rate ($E_{M,\ formaldehyde}$), and formaldehyde user retention rate ($R_{formaldehyde}$). Collectively, these three indicators serve as fundamental indicators for evaluating the impact of cigar smoke on indoor air quality and as pivotal input parameters for calculating indoor formaldehyde levels in residential and public places. This provides robust scientific support for exposure risk assessment, standard setting and improvement measures planning.

3 Results and discussion

3.1 Chemical Composition of cigar Emissions

Following the analysis of the primary emissions of cigars through the utilisation of chromatographic technology, the specific composition of 20 volatile compounds was ascertained. The data pertaining to these compounds is delineated in Figure 1. The compounds include isoprene, acrylonitrile, cresol, and other substances, which are categorised by the FDA as hazardous or potentially hazardous substances (HPHCs) in tobacco products and their smoke. Formaldehyde is a prevalent component of cigarette emissions and has been identified by the International Agency for Research on Cancer (IARC) as a carcinogen for humans [6]. In order to compare the emission characteristics of cigars with those of conventional cigarettes, a uniform measure was employed, with the number of micrograms of compounds contained in each cigarette being utilised as a uniform metric. For conventional cigarettes, the most recent aggregated data was referred to in order to determine the average concentration of their mainstream smoke. This provides a reliable basis for studying the potential harm to human health from different tobacco products.

The levels of VOCs emitted by cigars are typically one to two orders of magnitude higher than those of

cigarettes. However, cigarettes outperform cigars in certain VOCs, such as acetaldehyde, acetone, acrolein, crotonaldehyde, and butyraldehyde. This may be related to the low sugar content of cigar tobacco. Furthermore, cigars exhibit slightly higher levels of phenols during combustion, which may be attributable to factors such as the processing of cigar tobacco, the combustion conditions, or the chemical composition of the cigar.

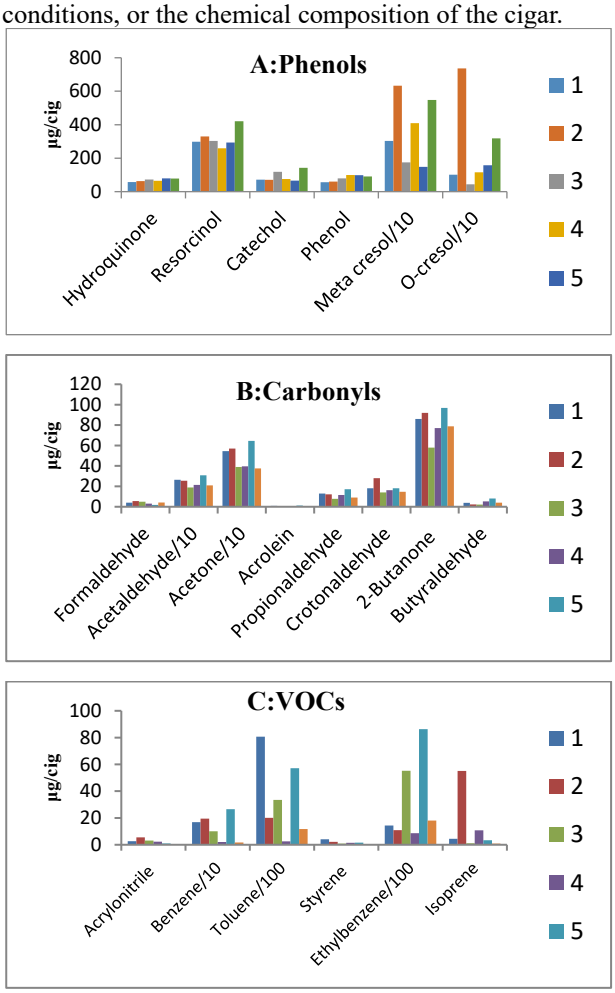

Figure 1. Measurement of Chemical Constituents in Mainstream Emissions from Cigars (µg/cig)

3.2 Predicted Impact on Indoor Air Quality

The present study set out to investigate the specific effects of cigars on indoor air quality. To this end, formaldehyde exposure was measured and indoor concentrations were predicted in residential and public spaces, with particular attention paid to the use of two cigars per day in residential settings. Figure 2 shows the average maximum indoor formaldehyde concentration over an eight-hour period at different indoor space sizes and ventilation efficiency. The data presented in Figure 2 are critical for deepening understanding of cigar effects, assessing health risks, and designing air quality management programs.

The Y-axis air change rate range encompasses typical residential values, with the X-axis denoting small to medium interior space volumes. To illustrate this, consider a master bedroom measuring 20 m^2 (~50 m^3) and a studio spanning 45 m^2 (equivalent to around 115 m^3). According to the standards established by the Office of Environmental Health Hazard Assessment (OEHHA), the 8-hour and chronic inhalation reference exposure level (REL) for formaldehyde is 9 µg m^{-3}. In confined spaces with inadequate ventilation, it is possible for formaldehyde concentrations to exceed the standard. This study estimated steady-state indoor formaldehyde concentrations in public places where cigar use is permitted, such as bars, in order to analyse the effects of cigar use on indoor air quality.

In their seminal study, Logue provided detailed parameters for 17 bars in Austin, Texas, including indoor space size, air flow rate, and the number of smokers. The present study utilised these parameters to assess the indoor formaldehyde concentrations in these bars. The results demonstrate that the indoor formaldehyde concentrations approach the chronic inhalation REL of 0.35 µg m^{-3} for OEHHA and exceed this limit in at least one scenario. This highlights the potential hazards of cigar use to indoor air quality and public health. The assessment demonstrated that the quality of indoor air in residential and public areas could be compromised, with individuals who do not utilise mobile phones potentially being exposed to harmful concentrations of carbonyl compounds and other VOCs. However, the simple box model is constrained in its capacity to delineate the uneven distribution of pollutants, particularly in its inability to account for elevated exposure levels in proximity to the source.

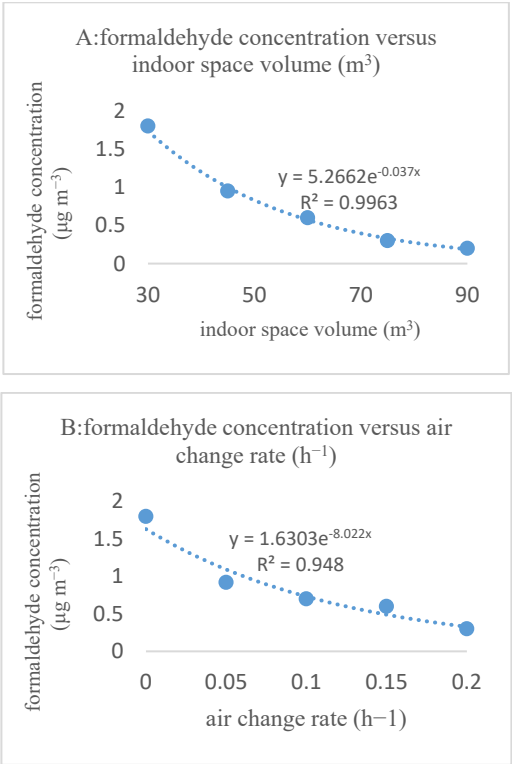

Figure 2. Indoor air formaldehyde levels (µg m^{-3}) were estimated using a model that considers daily cigar use (averaging 2 sticks), air exchange rate (h^{-1}), and indoor space volume (m^3)

4 Conclusion

The findings of this study demonstrate that the impact of cigars on users and bystanders is consistent with the findings of previous studies and focuses on the emission effects of exhaled mainstream cigar smoke in an indoor environment. Through the analysis of pollutant concentrations in different situations, a more detailed understanding of the specific mechanism of cigar use on indoor air quality is obtained, which provides a robust scientific basis for the development of policy measures and practical operations aimed at protecting the non-smoking population. Despite the findings of numerous studies indicating higher emissions from cigars in comparison to conventional cigarettes, direct comparisons between the two are seldom undertaken. The present study is constrained to the exploration of partial chemical emissions under specific conditions, thus failing to address particulate emissions that have been the subject of evaluation in other studies. When aerosol and particulate matter components, particularly PM2.5, are taken into consideration, cigar emissions may potentially exert an even more deleterious effect on human health.

References

1. Hu Y., Chen Yanming, Dong X., et al: Discussion on the production technology of high quality cigar tobacco. An hui nong xue tong bao 29, 27-29+33 (2023).
2. Wei Y., Xin Y., Liu X., et al: Domestic Cigar Tobacco Research Situation - Bibliometrics Based on CNKI Database. China Agricultural Information 34, 27–36(2022).
3. Yu H., Liu Y., Shang M., et al: Inter-origin differences in cigar tobacco based on aroma-causing component analyses. Tobacco Science & Technology 54, 58–71(2021).
4. Schaller JP, Keller D, Poget L, et al: Evaluation of the Tobacco Heating System 2.2. Part 2: Chemical composition, genotoxicity, cytotoxicity, and physical properties of the aerosol. Regulatory toxicology and pharmacology 81, 27−47(2016).
5. Jaccard G, Tafin Djoko D, Moennikes O, et al: Comparative assessment of HPHC yields in the Tobacco Heating System THS2.2 and commercial cigarettes. Regulatory toxicology and pharmacology 90,1−8 (2017).
6. K E S, Sinan S, Jack P, et al: Secondhand electronic cigarette aerosol in vehicles impacts indoor air quality. [J]. Drug and alcohol dependence, 250110889-110889 (2023).