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Emission of Dust and VOCs as Burning Incense Under Ventilation Conditions

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Abstract: This study determined emissions of incense burning, a traditional worship activity in Asian countries, under different ventilation conditions. The experiments were conducted in a chamber with a volume of 1 m^3 (1×1×1 m^3) without ventilation or under mechanical ventilation (6 m^3/h). There were four different types of traditional and aromatic incense in terms of length (in centimeter) and color, including 27.0 cm (traditional Inc1 - yellow), 21.5 cm (aromatic Inc2 - brown), 30.0 cm (aromatic Inc3 - dark yellow) and 19.0 cm (traditional Inc4- dark red color). The incence was placed and lighted at 0.5 m in height inside of the chamber. PM10 and PM2.5 were directly monitored in the whole process of incense burning using Air Quality Detector (GM8803 and SIBATA - LD-5R) at the same position of 0.5m in height. VOCs was measured by chromatography at three different periods, i.e., before the incense was lighted, during the process of burning, and after the incense burned out. Study results showed that the variation of PM concentrations was separated into three phases: (p1) PM concentrations quickly increased within 15 minutes after being lighted, (p2) PM concentrations were stable from 20 minutes to 35 minutes, (p3) PM concentrations decreased gradually. The maxinum concentrations of PM10 without ventilation for Inc1, Inc2, Inc3, Inc4 were 2138, 2293, 2259, 2210 µg/m^3, respectively; and they decreased about 40-70% under ventilation. The maxinum PM2.5 concentrations were about 870-1210 µg/m^3 under ventilation or without ventilation. VOCs ended up no Benzen emissions with all the types of experimental incense. Inc1 emitted HCHO concentrations from 4.8 ppm to 5.4 ppm, which was one of the two types containing highest concentrations of Formaldehyde. Meanwhile, Inc3 emitted the lowest VOCs concentrations among the three remaining types, and no Toluen was detected, which showed the optimum effect of clean incense in comparison with traditional one.

Key words: incense, VOC, particulate matter, ventilation, indoor pollution

1. Introduction

Research on indoor air pollution has been of interest since 1970s. Indoor air pollution problems are being concerned such as: cigarette smoke pollution, kitchen smoke pollution, respiratory dust pollution. Incense smoke is also one of the main sources of indoor air pollution in many countries around the world. Buddhism and countries practicing acts of ancestor worship, including Vietnam, use incense sticks religiously. Many types of incense sticks are impregnated with various chemicals. The basic ingredients of incense include resin, spices, fragrant wood, bark, herbs, seeds, roots, flowers, essential oils and synthetic substitutes used in the perfume industry [1].

Over the years, many Asian countries have conducted many studies on incense smoke such as Thailand, Taiwan, India, etc. These studies have published many important results related to incense smoke. The incense smoke contains Dioxin [2]. It contains many toxic that cause cancer and dangerous diseases (3;4;5;6). Incense smoke damages human genes [4]. A study reported that burning incense releases PM10 and many types of VOCs such as

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formaldehyde, benzene, toluene, xylene and TVOCs [7]. According to Friborg respiratory tract cancer has been linked to incense smoke. The cancer is more obvious with high frequency of burning incense. People regularly burning incense will increase the risk of contracting cancer [8]. Another study reported that lung cancer risk increases 4.5-5 times when people are exposed to incense smoke as compared with people who were not [9]. According to See, Incense smoke contains metallic content, and the emission content relies on the amount of metal in the incense [10].

Over the years, Vietnam has released a number of studies with significant results. According to research results conducted in residential areas of Hanoi, the burning of incense increased the geometric mean of indoor PM2.5 concentration by 120% with some adjusments for other factors [11].

Thus, incense smoke triggers numerous problems of indoor air pollution. This study focused on evaluating PM2.5, PM10 dust and VOCs emissions of incense smoke under ventilated and non-ventilated conditions in Ho Chi Minh city and neighboring provinces. VOCs, in the study were thoroughly concerned including Formaldehyde, Benzen, Toluen, and Xylene.

2. Materials and Methods

2.1 Experimental Incense

Types of incense used in the experiment are selected through surveys in Ho Chi Minh city and neighboring provinces. The survey process is divided into two parts, seller survey and consumer survey. The seller survey will gather opinions of 20 incense stores in Ho Chi Minh City and 20 stores in other provinces. Through this survey, popular types of incense will be determined on the market currently. The consumer survey will be conducted to assess their preferences for incense. Therefore, popular types of incense will be able to be represented as experimental samples. From the survey results, incense is separated into three main groups: traditional incense (the most popular), clean incense and chemical impregnated incense. The traditional incense is produced by traditional methods in Vietnam. The clean incense contains natural ingredients without scented chemicals. The chemical impregnated incense is produced by unclear materials, containing scent and coloring chemicals. According to the survey result, four typical types of frankincense sticks were selected to study. The physical characteristics of collected incense sticks are shown in the Table 1.

Table 1 Characteristics of experimental incense sticks.

ID No.	Category	Stick length (cm)	Stick Diameter (cm)	Color	Avg. burn time (min)
Inc1	Traditional	27	2	Yellow	76
Inc2	Aromatic (chemical impregnation)	21.5	3	Brown	51
Inc3	Aromatic (clean incense – natural ingredients)	30	1.5	Dark yellow	46
Inc4	Traditional	19	3	Dark red	58

2.2 Experimental Chamber

The experimental chamber is made of 5 mm-thick aluminum composite and 5 mm-thick acrylic resin with a cube-shaped volume of 1 m^3 ($1 \times 1 \times 1$ m^3). A door of the experimental chamber is designed on the top surface. The door is fixed with silicone sealant prior to conducting experiments. An air ventilation hole of 90cm is designed at the lowest corner of vertical wall of the chamber. The hole is installed with a 1-μm dust filter. An air exhaust hole with fans is installed at the highest corner of the wall, which is opposite the ventilation hole as presented in Fig. 1. The flow rate of the fans is 6 m^3/h — this air exchange rate suits the standards of Vietnam ventilation systems. The chamber has a front transparent panel for monitoring. Another hole is designed on the chamber wall to put burned experimental incense, i.e., ash into the chamber for preventing pollutants from penetrating the chamber.

The layout of the experimental model as shown in Fig. 1 is intended to simulate real conditions in Vietnam: main doors are arranged lower than ventilation fans; fans are usually located at the top of the room (1, 0, 1). The incense stick is placed at the base of the model (0, 0, 0) and the stick was lighted at the height half as high as the chamber (0, 0, ½) which is similar to Vietnamese worshiping areas (worshiping areas are half the height of the room). At the same time, the automatic air monitoring device is set far from exhaust source of the model, and it has the same height of the burning part of the incense (1, 1, ½), so that the experiments will have most objective results.

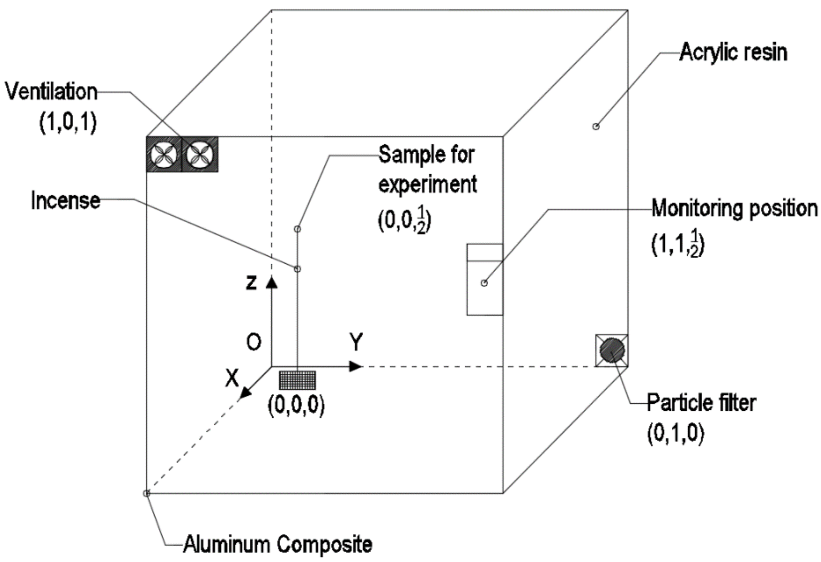

Fig. 1 Experimental chamber.

After every experiment finished, the chamber will be cleaned by running the exhaust fans continuously with the maximum capacity. When the pollution indicators inside of the model are similar to the outside conditions at the safety threshold, another experiment will be conducted.

2.3 Experimental Method

Incense sticks are burned under two experimental conditions: non-ventilation and mechanical ventilation. For the dust experiment, the data at the first minute of the process is the safe dust concentration being present in the environment before the burning takes place. This is the baseline data to compare with pollution concentration that would vary over time. In non-ventilated conditions, the chamber is sealed, and the fans are turned off. Under ventilation conditions, the exhaust fans will run in 15 minutes in advance and after conducting each experiment in order to clean the experimental chamber. The temperature and humidity inside of the chamber are recorded by relative humidity and temperature monitor, PM2.5 and PM10 are monitored by air quality detectors (GM8803 and SIBATA-LD-5R with range of 0-5000 μg/m^3) with the frequency of 1 time/min. These monitors are set at 0.5 m in height. Each experimental incense stick is placed at 0.4-0.6 m inside of the chamber. Each experiment will perform one incense stick. Experiments will be performed three times for each type of incense under the ventilated condition for accurate results. Chemical components of the incense such as total P, N, C, S are analyzed by CHNSO analyzer (Thermo Scientific). The incense samples will have been removed their bottom parts before being analyzed.

For VOCs experiments, samples are collected at the model with activated carbon KIT, and they will be analyzed in the laboratory by chromatography. For each type of incense, three samples of incense are collected under three different ventilation conditions (before it is lighted, while it is burning, and after it burns out), and the performance will be repeated three times to ensure the accuracy of the experiment.

3. Results and Discussion

3.1 Subtances of Incense

The main materials used to produce incense are natural sources with a high percentage of carbon as presented in Table 2. Most types of incense are mixed with phosphorus to burn easily. The burning time of an incense stick depends on length, diameter and phosphorus content. According to the experimental results, the burning time of Inc3 is the shortest among the four 4 types due to its highest phosphorus content. The high amount of phosphorus is thanks to chemical ingredients so that the incense is able to burn well and completely, also its color fades to serve the purpose of having no smoke as well as no ash. Since burning incense sticks can emit a lot of flying smoke and bottom ash, compounds of smoke have been removed from materials used for incense production. The source of particulate matter when burning incense is cellulose (carbon substanc). The percentage of nitrogen and sulfur is lower than the carbon percentage, which indicates that natural wood powder used to produce incense contains significant content of cellulose. This means that particulate matter mainly contains cellulose.

Table 2 Total chemical subs contained in the incense types.

Incense	Chemical component			
	P (mg/kg)	N (% mass)	C (% mass)	S (% mass)
Inc1	1.76	0.25	47.30	ND
Inc2	1.81	1.24	37.90	ND
Inc3	57.65	0.66	39.40	ND
Inc4	6.94	0.72	41.53	ND

Note: ND: non detective.

3.2 PM 2.5 and PM 10 Concentrations Without Ventilation

3.2.1 INC1

In view of the results, the burning time of Inc1 is the longest, from 75 to 76 minutes. There is a difference of dust concentrations between PM10 and PM2.5 under non-ventilated and mechanically ventilated conditions. The dust-emission process of Inc1 takes place in four phases: linear increase, unstable increase, equilibrium, and linear decrease. Under the non-ventilated condition, PM10 dust concentration can reach a maximum of 2138 μg/m^3. At the equilibrium state, the emission peak has an average concentration of over 2000 μg/m^3. Under the mechanically ventilated condition, the PM10 dust concentration of N1 incense is usually stable in the range of 900-1200 μg/m^3, and it decreases by 42.26% compared to the non-ventilated condition. PM2.5 dust concentration can reach a maximum of 1046 μg/m^3. At its equilibrium state, the average concentration of PM2.5 is over 950 μg/m^3. Under the mechanically ventilated condition, the PM2.5 dust concentration of Inc1 is usually stable from 800 to 1000 μg/m^3 and the concentration is reduced by 4% compared to the PM2.5 dust concentration under the non-ventilated condition.

3.2.2 INC2

Based on the shape of the graph below, the dust concentration of PM10 under the non-ventilated condition is the highest, and it is separated into three phases: linear increase, equilibrium, and linear decrease. Under the mechanically ventilated condition, it is divided into two phases: linear increase (phase 1) and equilibrium (phase 2). Under the non-ventilated condition, PM10 dust concentration can reach the highest point of 2293 μg/m^3, and the average dust concentration at the emission peak is over 2100 μg/m^3. The pollution concentration under the non-ventilated condition is 55.96% higher than the concentration under the ventilated one. Under the mechanically ventilated condition, the PM10 dust concentration of Inc2 is usually stable at the average of 1000 μg/m^3. PM2.5 dust under the non-ventilated condition experiences two phases: linear increase and linear decrease. Under the other condition, the PM2.5 dust concentration of Inc2 goes through two phases: linear increase and equilibrium. Under the non-ventilated condition, the highest dust concentration that PM2.5 can reach is 1114 μg/m^3, and the average concentration at the emission peak is always above 1000 μg/m^3. The dust concentration of PM2.5 under the mechanically ventilated condition falls by 13.8% compared to the non-ventilated one. Under the condition of mechanical ventilation, the PM2.5 dust concentration of Inc is always stable in the range of 800-900 μg/m^3.

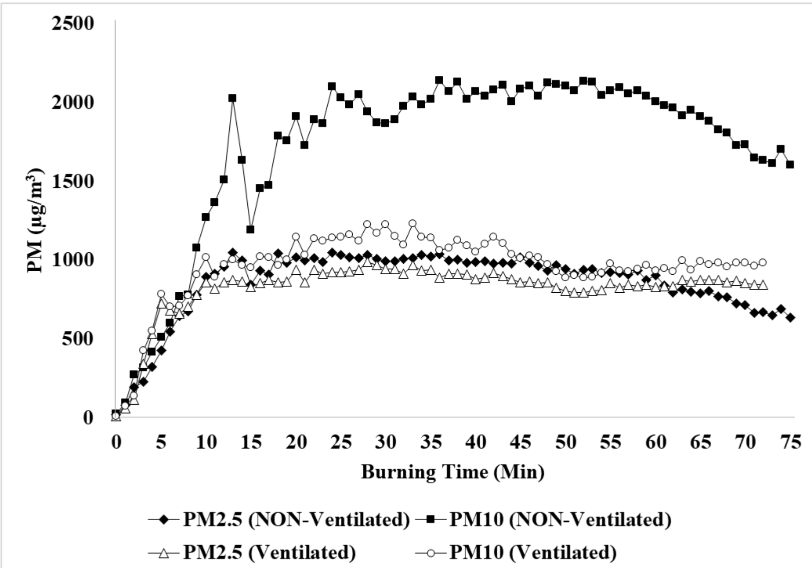

Fig. 2 Variation of PM following burning time without ventilation (Incense 1).

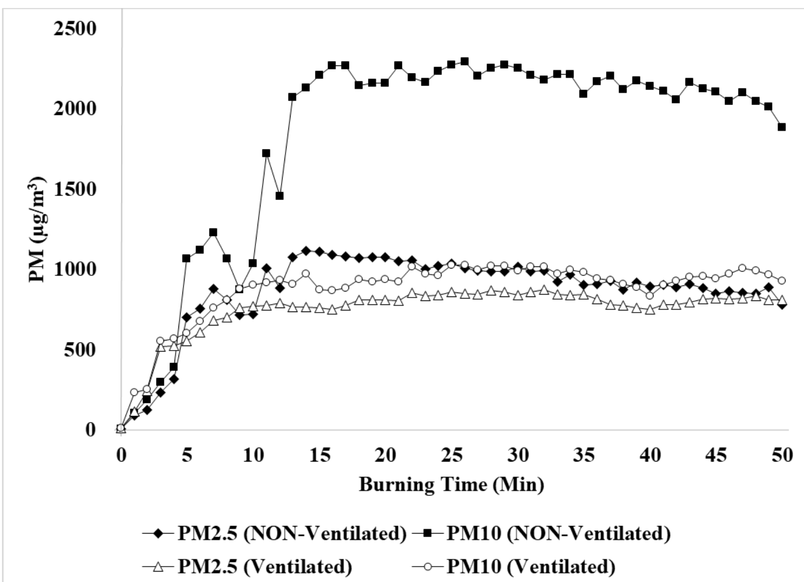

Fig. 3 Variation of PM following burning time without ventilation (Incense 2).

3.2.3 INC3

According to the graph, it illustrates the fluctuation in the dust concentration of Inc3 under the non-ventilated condition during the burning process Under the mechanical ventilation, the concentration linearly increases up to 500 μg/m^3, and it is stable at this concentration level throughout the burning process. Under the condition of no ventilation, PM10 dust concentration can reach the highest level of 2259 μg/m^3, and it drops by 67% under the mechanical ventilation compared to the other one. Regarding PM2.5 dust, under the non-ventilated condition, the strongest dust concentration that PM2.5 can arrive is 1038 μg/m^3, and the emission peak averages over 1000 μg/m^3 near the end of the process. The pollution concentration under the mechanical ventilation declines by 46.24% in comparision with the opposite one. After the experiment, there is a linear increase in Inc3 emission since the incense smoke contains a small amount of natural aromatic oil as well as a tiny cross-section and low burning volume, which makes incense smoke paler and heavier than air. For it is heavier than air, incense smoke will settle at the bottom of the chamber, and the volume of gas will rise over time inside of the chamber. Therefore, consumers are not be able to sense the smoke emission while incense is burning.

3.2.4 INC4

The emission process of Inc4 is similar to Inc1. Under the non-ventilated condition, the concentration of PM10 dust can get at 2210 μg/m^3, and its emission peak dust concentration averages over 2000 μg/m^3. Under the same mechanial ventilated condition, the highest PM10 concentration is 1470 μg/m^3, a decrease of 32.46% compared with the non-ventilated one. PM2.5 dust under both ventilation conditions similarly emit the average concentration level of 1000 μg/m^3.

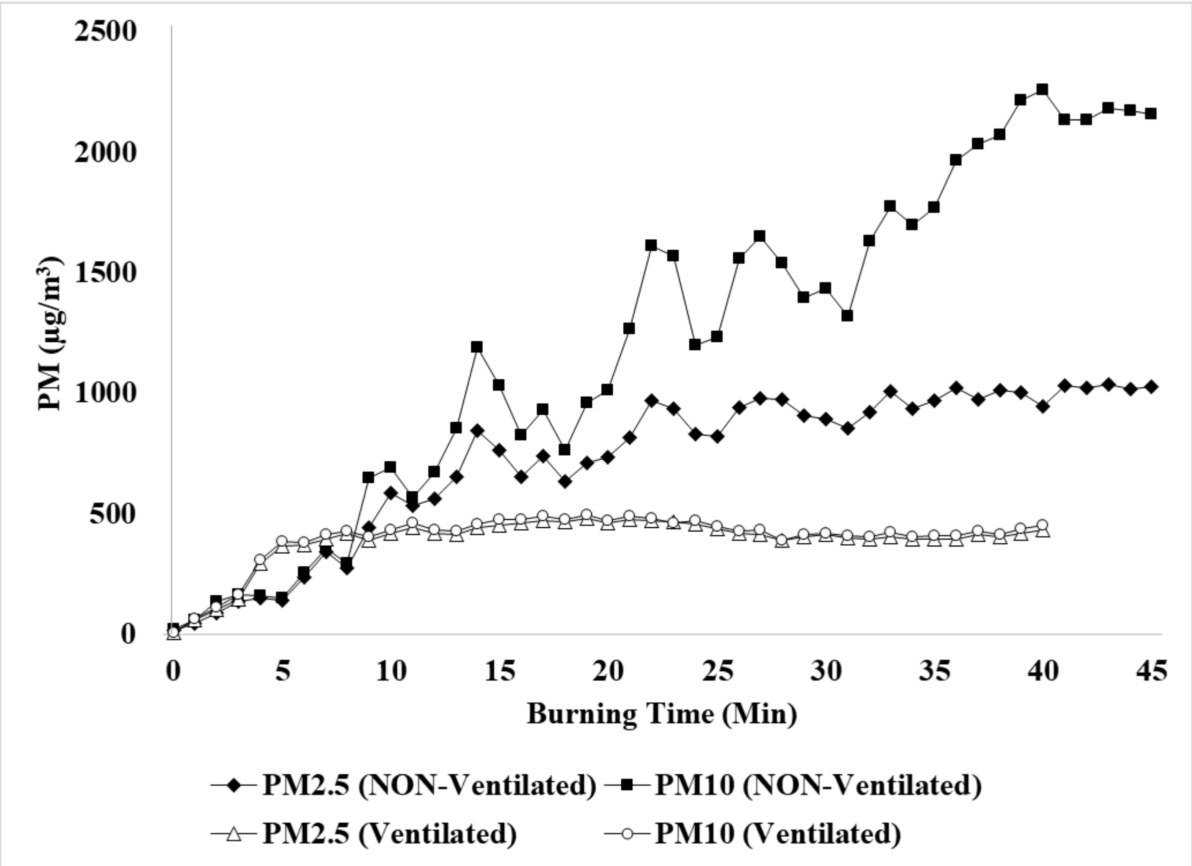

Fig. 4 Variation of PM following burning time without ventilation (Incense 3).

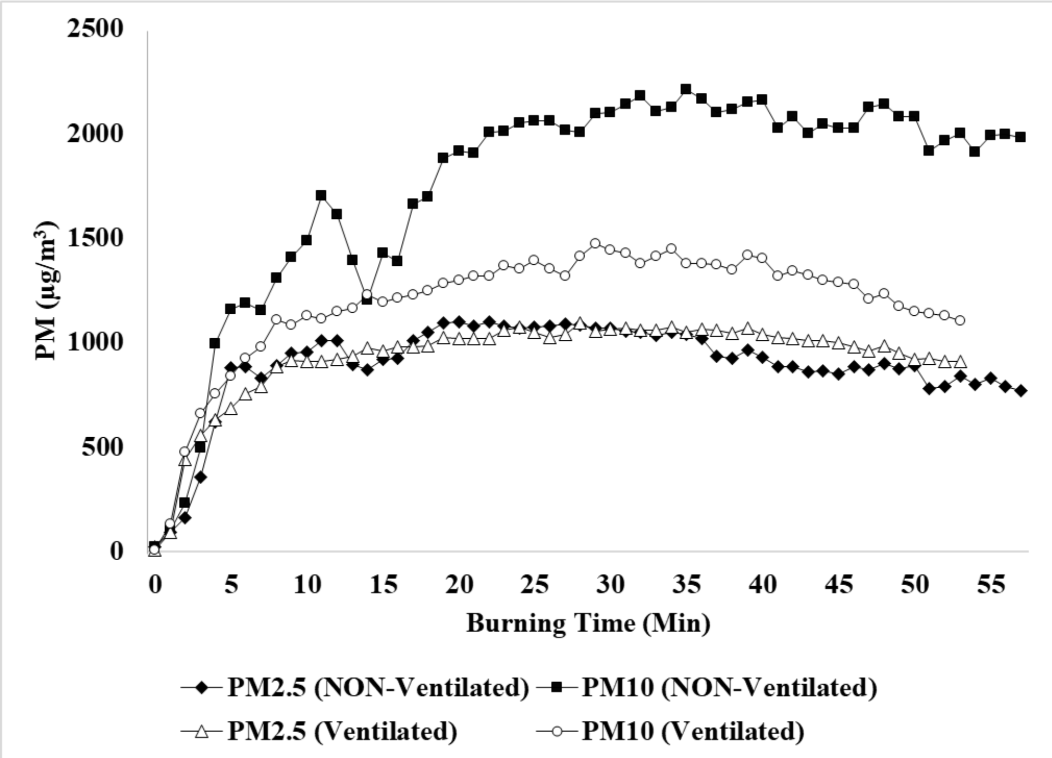

Fig. 5 Variation of PM following burning time without ventilation (Incense 4).

3.3 Dust Emission Concentration Over Time

According to the dust decay equation [12]:

$$C_{(t)} = C_0 \times e^{-kt}$$

In the equation t is the time (minutes); Co is the initial concentration (µg/m^3); Ct is the concentration at the time t (µg/m^3); k is the decomposition coefficient (time-1). From the equation, the volume of settled dust can be calculated for each phase of the burning process. Through to the results of the dust volume emitted per minute and the settled dust volume, the average load can be calculated for each type of incense per minute as follows:

Table 3 Dust emission concentration over time of Incense.

Type of incense	Burning Time (minutes)	Load (µg/min)		Dust emission volume (µg/stick)	
		PM10	PM2.5	PM10	PM2.5
Inc1	76	117	34	8892	2564
Inc2	51	75	32	3835	1620
Inc3	46	84	29	3881	1328
Inc4	58	82	29	4773	1676

According to the figures, Inc1, with PM10 and PM2.5, performs the largest dust emission loads of 117 µg/min and 34 µg/min, respectively. Inc2 emits the lowest load, only 75 µg/min. From the result of the loads, the volume of dust emitted from an incense stick can be calculated in the chamber. It is Inc1 incense that releases the highest volume of dust, 8892 µg/stick with PM10 and 2564 µg/stick with PM2.5. Inc2 and Inc3 similarly release PM10 dust emission volume per stick. Dust emission volume relies on loads and burning time of each type of incense. From the above results, the pollutant emission is of high level in common types of incense on the market. Meanwhile, in spite of having lower level of pollutant concentration, clean incense poses a danger to human health as high as the common types.

3.4 Variation of VOCs Concentration

Through chromatographically analyzed results, all types of incense end up emitting no Benzene. The HCHO concentration of Inc1 is in the range of 4.8 ppm to 5.4 ppm, which is one of the two types with the highest concentration of Formandehyde (Inc4 results in the similar measurement). The lowest concentration of VOCs emission is Inc3, and no Toluen is detected.

Table 4 Concentrations of VOCs in non-ventilated conditions.

	INC1			INC2			INC3			INC4		
	Before Burning	Burning	Afer burning	Before Burning	Burning	Afer burning	Before Burning	Burning	Afer burning	Before Burning	Burning	Afer burning
HCHO	ND	3.3116	4.6587	ND	2.8079	3.3401	ND	1.6334	2.9384	ND	3.3492	4.8929
XYLENE	ND	0.5461	0.8402	ND	0.5982	0.9064	ND	0.356	0.4604	ND	1.1461	1.3486
TOLUEN	ND	0.3509	0.734	ND	0.2617	0.3808	ND	ND	ND	ND	0.2833	0.6997
BENZEN	ND	ND	ND	ND	ND	ND	ND	ND	BD	ND	ND	ND

Table 5 Concentrations of VOCs under mechanical ventilation.

	INC1			INC2			INC3			INC4		
	Before Burning	Burning	Afer burning	Before Burning	Burning	Afer burning	Before Burning	Burning	Afer burning	Before Burning	Burning	Afer burning
HCHO	ND	1.0587	1.3459	ND	0.7044	1.0872	ND	0.5549	0.7163	ND	1.1804	1.7674
XYLENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOLUEN	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZEN	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

According to OSHA (Occupational Safety and Health Administration), HCHO concentration exposed within an average limit of eight minutes is 0.75 ppm, and the short-term exposure limit within 15 minutes is 2 ppm. Thereby, pollutant concentration of HCHO in all types of incense entering the atmosphere under the non-ventilated condition exceeds the allowable limit. Under the condition of mechanical ventilation, this excessive concentration is greatly reduced during the process of burning incense, and guaranteed to be below its hazardous threshold. Xylene and Toluene in incense types are all at the safe threshold in case of using one single incense stick at a time.

4. Conclusion

This research assessed variation of PM concentrations during the process of burning different types of incense. Four kinds of traditional and aromatic incense sticks with different length and color were collected for experimental purposes. Study results showed that variation of PM concentrations were seperated into three phases: (p1) PM concentrations increased quickly within 15 minutes after being lighted, (p2) PM concentrations were stable within 20-35 minutes, (p3) PM concentrations decreased gradually. The PM concentrations under ventilation decreased 15-50% as compared with the ones without ventilation. For VOCs, the concentration of Formaldehyde emissions was the highest, which was mainly caused by the anti-termite preservatives of incense. As for other types of VOCs, they were all at the safe threshold when one single stick of incense was used at a time. In addition, the study also showed that setting mechanical ventilationin worshiping areas would significantly eliminate indoor polluant emission in the shortest amount of time. Accordingly, we can evaluate the time of preventing pollution under each ventilation condition to further clarify the effectiveness of ventilation measures.

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