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Simulated Study on Typical Sources of Volatile Organic Compounds (VOCs) in Indoor Air

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Abstract: In this paper, several simulated devices were constructed for determining components of organic vapors emitting from decorative materials, daily use chemicals and from common behavior of human beings, such as smoking and cooking. The VOCs were preconcentrated on activated carbon and then desorbed by carbon disulphide. The results were obtained by GC/MS analysis and computer searching. It can be concluded that the categories of the sources and the components of organic vapors in indoor air are very complicated, and different sources of VOCs in indoor air have their own emission characteristics.

Keywords: indoor air pollution, simulated device, VOCs

1. Introduction

Volatile organic compounds (VOCs) is made up of aliphatic hydrocarbons, aromatic hydrocarbons, chlorinated hydrocarbons, aldehydes, ketones, etc. They constitute an important fraction of indoor air pollutants. In recent years, greatly increased attention has been focused on VOCs[1-4]. The technique and procedure of determining the chemical composition and the amounts of the components of VOCs emitting from different materials have been reported[5-14]. As to keep the steady of different environmental factors which can affect the volatilization and transformation of the pollutants, according to the experiment requirements, we controlled the categories and the intensity of pollution source and we confined the pollution source to a limited space operating from external effect. By simulated equipment, we have put forward the mathematical model of emission rate of VOCs in indoor environment and found the regular pattern of the transformation of the pollutants emitting from different sources. All of this can be the theoretical basis of working out an effective measure to control the pollution.

2.Experiment

2.1 Sampling

We selected CX-100 (Xinhua factory, Taiyuan, China) as activated carbon sampling tube. Through successive sampling, we have determined the mean value during preconcentrated sampling time and improved the sensitivity of determination[15].

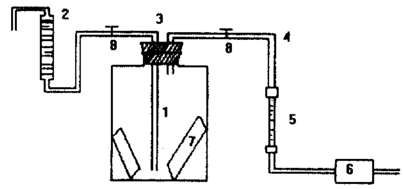
2.2 Conditions of GC/MS

All GC/MS analyses were performed by using Hewlett-Packard Model 5890 II GC/5970AMSD in the electron impact (EI) mode with a scan range of 20-450 amu. Injections (2ul) were employed at splitless mode into a HP-5 capillary column (50m in length, 0.32mm i.d., 0.52 um coating thickness: Hewlett-Packard Ltd.). The GC oven temperature program was 30℃(held for 2 min) followed by a temperature ramp at 4℃/min to 160 ℃ and at 10℃/min to 280℃. The injection port and GC/MS transfer line temperature were all held at 280℃. An autotune with perfluorotributyl-amine (PFTBA) was performed daily to calibrate the mass spectrometer.

2.3 Simulated method

2.3.1 Simulated study on decorative materials and daily-use chemicals

During simulated study, we select four typical pollution sources in indoor air. They are wall paper (plastic foam wall paper), floor leather (plastic), shoe polish (popular black shoe polish) and paint(alcohol acid mixing paint). The devices of simulated experiment are presented in *Fig. 1*. The whole installation which has two air vents are made up of glass and Teflon and its volume is 20 l. The inlet is the entrance of clean air and the outlet is the sampling hole. The preparation procedure of experiment materials are showed below. Cut the wall paper and floor leather into pieces of 20 cm × 20 cm, the three sides of each are sections. When doing experiment about paint and shoe polish, put all the materials mentioned before into simulated installation which has been already purified by clean air and close to these two air vents. After 24 hours, open two air vents and begin sampling.

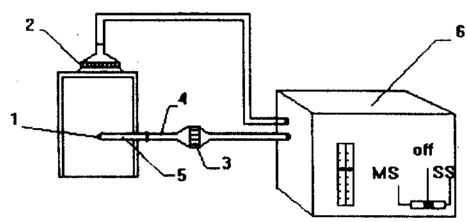


1. 20 l glass bottle 2. active carbon cleaning tube 3. inlet tube 4. outlet tube 5. sampling tube 6. pump 7. simulated materials 8. valve

Fig. 1 Diagram of simulated installation for VOCs determination

2.3.2 The simulated study on cigarette smoke

Besides decorative materials and daily use chemicals, common behaviors of human beings are also the important pollutant source in indoor air. For example, the environmental tobacco smoke (ETS) produced from smoking. Sidestream smoke (SSS), commonly defined as the smoke which issues from the product between puffs. Mainstream smoke (MSS) is defined as the smoke which through the char line during puff, then inhaled by the smoker. In order to study the environmental behavior of ETS, we selected the simulated installation presented in *Fig. 2(ISO 3308)*. Sampling hole 2 is used for collecting SSS, while 3 is used for collecting MSS and adsorb the organic compounds containing in the ETS with activated carbon.

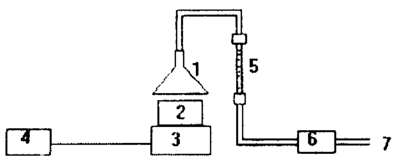


1. SSS sampling 2. head of SSS sampling 3. head of MSS ampling 4. cigarette holder 5. cigarette 6. sampler

Fig. 2 Diagram of simulated installation under smoking condition

2.3.3 The simulated study on kitchen oil smoke

Kitchen oil smoke is an important fraction of indoor air pollution source. The simulated device presented as *Fig.3* is used for the cooking oil smoke investigation. Put certain edible oil into frying pan 2 and heat it with heating furnace of which temperature can be controlled. Collect vapor phase organics in oil smoke with activated carbon tube, collect particulate phase organics in oil smoke with glass fiber filter, and then analyze the organics on filter and VOCs on activated carbon by using the same method as analyzing ETS.



1. sampling filter 2. pan 3. electric stove
4. voltage regulator 5. active carbon sampling tube
6. pump 7. outlet

Fig. 3 Diagram of simulated device for cooking smoke investigation

3. Results and discussion

3.1 The result of the simulated study on decorative material and daily using chemicals

The main categories of compound contained in wall paper, floor leather, shoe polish, and paint, etc. are presented in *Table 1,2,3,4*.

Table 1. The determination result of the VOCs from wall paper

Aliphatic (Alkanes)

Undecane; Heptadecane, 2,6,10,15-tetramethyl-; Tetradecane; Cyclopentane, 1-ethyl-2-methyl, cis-; Nonadecane; Cyclopropane, 1-methyl-2-octyl;

Alkenes

1,3,5-Cycloheptatriene, 7-ethyl; 5-Octadecene, (E)-; 1,13-Tetradecadiene;

Alkynes

1-Eicosyne;

Aromatic

Benzene, dimethyl-; Benzene, cyclopropyl-;

PAHs

1H-Benzotriazole, 5-methoxy-

Alcohols

1-Tetracosanol; Hexadecanol; 1-hexadexanol; 1-Hexacosanol; Hexadecanol;

Esters

1,2-Benzenedicarboxylic acid, butyl ester; Acetic acid, nonyl ester; Bis(2-ethylhexyl) phthalate (ACN);

Others

Butane, 1-isothiocyanato-; 2-Propenamide, N-(1-methylethyl)-;

Table 2. The determination result of the VOCs from floor leather

Aliphatic

Silane, ethenyldiethylmethyl-; Tetradecane; Pentadecane; 7-Hexadecene, (Z)-; 1-Heptene, 2-isohexyl-6-methyl-; 1-Eicosene; 11-Tricosene; 3-Eicosene, (E)-;

Aromatic

Benzene, 1-ethyl-3-ethyl-; Benzene, (1-butyloctyl)-; Benzene, (1-ethyldecyl)-; Benzene, (1-methylundecyl)-; Benzene, (1-pentylheptyl)-;

PAHs

3,8-Azo-4,7-methanocyclobuta[b]naphthlene

Alcohols

Benzeneethanol; 1-Heptanol, 2-propyl-;

Aldehydes

Cyclopropaneoctanal, 2-octyl;

Heterocyclic compounds

Benz[c]acridine, 5,10-dimethyl-; 3-methyl-2-phenylindole;

Esters

1,2-Benzenedicarboxylic acid, butylic; 1,2-Benzenedicarboxylic acid, bis(2-methyl oxyethyl)ester

Acid

Pentadecanoic acid; Benzoic acid, 4-cyano-, 3-chlorophenyl; Octadecanoic acid; 1,2-Benzenedicarboxylic acid, 3-nitro;

Table 3. The determination result of the VOCs from shoe polish

Alkanes

Nonane; 1-Iodo-2-methylundecane; Cyclohexane, butyl; Tetradecane; Cyclohexane, 1-(1,5-dimethylhexyl)-4-(4-methylpentyl)-; Cyclohexane, 1,2-dimethyl-3-pentyl-4-one;

Alkenes

5-Octadecene, (E)-; 1,13-Tetradecadiene; 7-Cyclohexadecane; 1,13-Tetradecadiene;

Aromatic

Benzene, dimethyl; Benzene, 1,2,3-trimethyl-; Benzene, methyl(1-methylethyl)-; Benzene, 1-methyl-3-propyl-; Benzene, 1-methyl-4-(1-methylethyl)-butyl;

Heterocyclic compounds

1H-Pyrazole, 4,5-dihydro-4,5-dimethyl;

Alcohols

1-Hexadecanol; Octadecanol; 1,14-Tetradecanediol; Ethanol, 2-(9-octadecenyloxy)-;

Esters

Myristic acid, 9-octadecenyl ester; 1,1-Dodecanediol, diacetate; 1,2-Benzenedicarboxylic acid, butyl ester;

Aldehydes

Octadecanal; 9-Octadecenal; Tetradecanal; Cyclopropaneundecanal, 2-nonyl-;

Ketones

Cyclohexadecane;

Acids

Tetradecanoic acid; Hexadecanoic acid; 14-Pentadecenoic acid;

Amine

Dodecanamide, N,N-bis(2-hydroxyethyl)-;

Table 4. The determination result of the VOCs from paint

Alkanes

Nonane; Octane, 3,6-dimethyl-; Heptane, 3-ethyl-2-methyl-; Decane, 4-methyl-; Dodecane; Tetradecane;

Alkenes

2-Octene, 2,6-dimethyl-; 1-Cyclohexane, (1,1-dimethylpropyl)-; 2-Octene, 4-ethyl-; Cyclohexane, 1,1-dimethyl-2-propyl-; 1H-Indene, 2,3-dihydro-1,3-dimethyl-;

Aromatic

Benzene, ethyl-; Benzene, dimethyl; Benzene, 1,3,5-trimethyl-; Benzene, 1,2,4-trimethyl; Benzene, 2-ethyl-1,4-dimethyl-; Benzene, methyl(1-methylethyl)-;

Heterocyclic compounds

Oxazole, 4,5-dimethyl-; 1H-Imidazole, 2-ethyl-4,5-dihydro-4-methyl;

Ketones

Cyclopentanone, 2-methyl-4-(2-methylprotyl);

Alcohols

1-Decanol, 2-ethyl-; Ethanol, 2-(octyloxy)-;

So it can be concluded that the decorative materials (such as wall paper, floor leather and paint etc.) emit little aldehydes, much aliphatic hydrocarbons, aromatic hydrocarbons. While shoe polish emit not only hydrocarbons but also much oxygen-containing compounds such as aldehydes, ketones, alcohols, esters, etc. These four kinds of material are all the pollutant source indoors.

3.2 The result of simulated study on cigarette smoking

ETS is a kind of indoor air pollutants with quite toxicity and it exists widely in air. There are the compounds of pungent gases and tar particulate and they can cause disease of respiratory system and lung cancer. Through simulated study, 40 kinds of organic compounds have been detected in MSS and 50 kinds in SSS. The kinds of compounds are shown in *Table 5*. Through comparison, we can see that the composition of organics in MSS and SSS are different.

The common point is that they all have more than 50% aliphatic hydrocarbons, and simultaneously, contain alcohols, aldehydes, ketones, esters, organic acids, oxygen or nitrogen-containing compounds, aromatic hydrocarbons, amine, heterocyclic compounds and polycyclic aromatic hydrocarbons (PAHs). But there are more kinds of aromatic hydrocarbons (18%) in SSS. It is much more than that (7.5%) in MSS. Besides this, the kinds of oxygen-containing compounds in MSS (27.5%) are more than that in SSS (18.0%). But MSS and SSS all produce much VOCs when burning. Therefore, it can be concluded that cigarette smoke is one of important source of VOCs indoors[12].

Table 5. Qualitative detection of VOCs in MSS and SSS*

	MSS Number	MSS %	SSS Number	SSS %
Saturated aliphatic hydrocarbons	12	30	14	28
Unsaturated aliphatic hydrocarbons	9	22.5	3	26
Aromatic	3	7.5	9	18
PAHs	1	2.5	--	--
Heterocyclic compounds	2	5	2	4
Alcohols	5	12.5	4	8
Aldehydes	1	2.5	--	--
Ketones	1	2.5	1	2
Esters	3	7.5	3	6
Acids	1	2.5	1	2
Amine	1	2.5	2	4
Terpene	1	2.5	1	2
Total	40	100	50	100

*: --indicates that not detected

3.3 The result of simulated study on kitchen oil smoke

It is well known that cooking oil can produce smoke and it contains many kinds of poisonous organics, which can irritate people's eyes and respiratory system and cause cancer, gene mutation, cardiovascular diseases. In simulated study, we have determined the organics in lower temperature oil (LTO) and in higher temperature oil (HTO) respectively.

The LTO means the oil hardly produce any smoke but oil smoke with fragrant under the temperature limit of 100-140℃. While the HTO means the oil begin producing smoke under the tempreture of 230℃. By GC/MSD qualitative analysis, There are 42 kinds of organics in smoke of LTO and 73 kinds of organics in smoke of HTO. So it can be concluded that under higher tempreture, cooking oil can produce many kinds of organics. The numbers and the proportion of organics in lower and higher temperature oil smoke are shown in *Table 6*.

Table 6. Qualitative detection of VOCs in HTO and LTO smoke*

	LTO Number	LTO %	HTO Number	HTO %
Saturated aliphatic hydrocarbons	10	24	17	23
Unsaturated aliphatic hydrocarbons	10	24	21	29
Aromatic	--	--	4	5
Heterocyclic compounds	1	2	5	7
Alcohols	6	14	6	8
Aldehydes	8	19	11	15
Ketones	3	7	4	5
Esters	3	7	4	5
Terpene	1	2	--	--
Amino- acid	--	--	1	1
Total	42	100	73	100

*: -- indicates that not detected

From *Table 6*, we can see that the kitchen oil smoke contains many kinds of saturated and unsaturated aliphatic hydrocarbons, aldehydes, alcohols. Moreover, the content of hexanal is very high in the smoke of lower and higher temperature oil. There are more kinds of organics in smoke of HTO than that in smoke of LTO. In smoke of HTO, the number and proportion of unsaturated hydrocarbons, aromatic hydrocarbons, heterocyclic compounds are higher than that in smoke of LTO, mainly are the number of oxygen-containing organics such as aldehydes, ketones, esters, etc.

From the comparison, it can be seen that under high tempreture , oil can produce more kinds of organics and some compounds in oil can happen certain chemical reaction (for example, oxidizing reaction, etc.) and produce some oxygen-containing compounds (such as aldehydes, ketones, etc.) or produce unsaturated organics (such as alkenes, alkynes, etc.) by dehydrogenation. Linear alkanes hydrocarbons can produce alkenes by fragmentation or branch chain hydrocarbons by isomerization.

From the analysis mentioned, we can concluded that kitchen oil smoke is one of important pollution source of VOCs indoors. Smoke of HTO contains more kinds of VOCs, which will cause serious indoor pollution. Therefore, how to prevent the production of kitchen oil smoke, especially the production of smoke of HTO and control the ventilation condition indoors is very important in improving the quality of air indoors.

4. Conclusions

With the widely use of chemicals, there are all kinds of VOCs pollutants in indoor air. While in general, organic compounds such as those dominate the VOCs in building are considered to have low toxicity. With the change condition of light and heat, the strength of VOCs pollution source will change accordingly.

The behaviors of human beings always accompany with the emission of VOCs.

People spend a major portion of their time indoors. Though not all the VOCs indoors do harm to human beings, but if people exposure in lower concentration organic pollutant long time, their health must be affected and the life quality must be decreased.

To study on the environmental behavior of VOCs indoors, it is necessary to pay special attention to source, transformation and sink. In this paper, we have study several kinds of indoor VOCs pollution source by simple method. It is significant in methodology and its results can be the base of deeply studying the transformation and sinks of pollutants.

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