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Impact of HVAC filter on indoor air quality in terms of ozone removal and carbonyls generation

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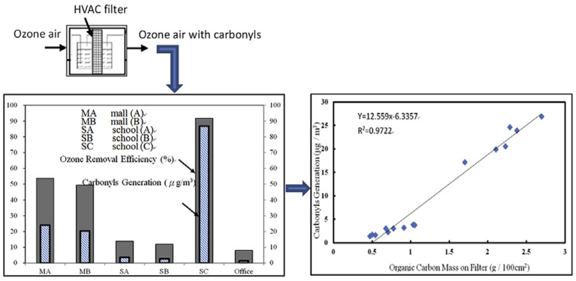
HIGHLIGHTS

- A positive correlation between ozone removal efficiency and carbonyls generation.
- A positive correlation between the mass of organic carbon and ozone removal.
- A positive correlation between the mass of organic carbon and carbonyls generation.
- No significant linear correlation between surface areas of dusts and ozone removal.
- Dust compositions have greater influence on ozone removal than dust surface area.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims at detecting ozone removal rates and corresponding carbonyls generated by ozone reaction with HVAC filters from various building, i.e., shopping mall, school, and office building. Studies were conducted in a small-scale environmental chamber. By examining dust properties including organic carbon proportion and specific surface area of dusts adsorbed on filters along with ozone removal rates and carbonyls generation rate, the relationship among dust properties, ozone removal rates, and carbonyls generation was identified. The results indicate a well-defined positive correlation between ozone removal efficiency and carbonyls generation on filters, as well as a positive correlation among the mass of organic carbon on filters, ozone removal efficiency and carbonyls generations.

1. Introduction

Heating, Ventilating and Air Conditioning (HVAC) systems are widely used in certain parts of the world. Supply air filtration is usually needed to prevent air handling unit and ducts to get dirty. However, supply air filters are usually the main odor source and degrade the perceived quality of ventilation air (Alm, 2001; Clausen, 2004), as well as contribute to sick building syndrome symptoms and negatively impact occupant performance (Clausen et al., 2002; Wargocki et al., 2004; Wyon et al., 2000).

After several months of operation, particles captured by an air filter can be significant relative to the filter's cross-sectional area (Weschler, 2003). Hyttinen et al. (2002, 2007) demonstrated that

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aldehydes, alcohols, carboxylic acids, terpenes, phthalates, aromatic hydrocarbons and nitrogen-containing organic compounds were the main emission products in the thermodesorption analyses of the filter dust. Many of these compounds have low odor threshold values and therefore, contribute to the odor released from the filters, especially aldehydes seems to mainly contribute to the odor formation. In addition, part of these organic compounds emitted by captured particles can react with ozone contained in the air passing through the filter, which results in ozone removal. However, the products of ozone oxidation reactions may desorb to airstream and degrade perceived air quality (Weschler, 2004). The extent to which the chemical processes on used filter surfaces may depend on the amount of particulate mass captured on the filter surface (Hyttinen et al., 2006; Bekö et al., 2007), location, season, filter type, manufacturing process (Hyttinen et al., 2001, 2007; Zhao et al., 2007; Buchanan et al., 2008), and position of the filter in the ventilation unit (Bekö et al., 2008). Bekö et al. (2007) indicated two different removal mechanisms associated with ozone removal efficiencies for filters – reactions with compounds present on the filter media following manufacturing and reactions with compounds associated with captured particles. In addition, a filter's exposure history subsequently affects the amount of oxidation products produced when ozone-containing air flows through it.

Destaillats et al. (2011) suggested that hydrolysis of filter binder or tackifier additives may be a significant formaldehyde source. Ozone can also react with dusty air filters and small fraction of formaldehyde is produced in these reactions (Hyttinen et al., 2003, 2006). In addition, ultrafine particles (i.e. secondary organic aerosols, SOA) are formed when VOCs are oxidized by ozone in air. However, Pinto et al. (2007) did not observe any secondary aerosol formation when terpenes were emitted into a test chamber at ozone concentration of 100 ppb, whereas clear particle formation was observed at higher ozone concentration of 200–400 ppb. These reaction products which may include formaldehyde, organic nitrates and secondary organic aerosol are considered as possibly carcinogenic to humans (Nazaroff and Weschler, 2004; Lamble et al., 2011). However, there is limited published information regarding ozone removal rates and corresponding carbonyls generated by ozone reaction with HVAC filters from various building.

The aim of this study was to describe ozone removal and carbonyls generation on dusty air filters from different locations. The organic carbon and surface area of the deposited dust/particles on air filters were analyzed and their respective influence on the carbonyls generation was investigated at the same time.

2. Experimental methodology

2.1. Experimental system

Fig. 1 depicts the experimental system. Laboratory experiments were conducted in a small stainless steel chamber with a vertical filter holder installed in the middle. Each test filter was fastened in the filter holder. The filter holder has a hollow center in round shape with a diameter of 18 cm. The chamber system was set up at 26 °C, 60% relative humidity, and the input ozone concentration was 60 ppb. All air entering the chamber was pre-filtered through silica gel, activated carbon, and HEPA in order to get clean. The air was pulled through a vacuum pump with a stable volumetric flow rate and was mixed with ozone generated by an ozone generator (2B Technologies, Model 306). The mixed air was then conveyed through the chamber system, which is into the upper stream chamber, through the filter, out of the downstream chamber. Ozone concentrations upstream and downstream of the filter were continuously monitored and recorded by UV ozone analyzers (2B Technologies, Model 202) with sampling time intervals of 10 s. Each experiment lasted for 12 h. The face velocity was 1.64 cm/s. The air flow rate of 25 L/min through the filter was confirmed after each experiment with a bubble flow meter (Sensidyne, Model Gilibrator 2) at the outlet of the downstream chamber.

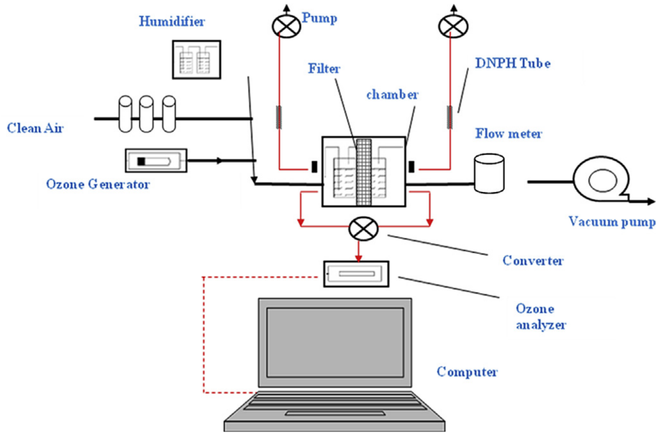

Fig. 1. Experimental system.

2.2. Test filters

Filters from three different types of buildings (i.e., shopping mall, school, and office building) were tested. Some important filter properties are described in Table 1. All filters were used after the mixing of supply and recirculation air in HVAC system. Filters from Mall (A) and Mall (B) were mainly made of polyester fiber with a thickness of 0.015 m. They had been used in Mall for two and a half months. Mall A is located in the middle of heavy traffic area while Mall B is in suburb area. In both Mall A and Mall B, most restaurants are located on the 1st floor and several on the 3rd floor. Thus, filters from these two floors may capture more particles resulting from the exhaust of cooking. Moreover, filters from the 1st floor in Mall A may get accumulated some particles resulting from heavy traffic nearby. Filters from School (A) and School (B) were mainly made of glass fiber with a thickness of 0.051 m. They had been used in school for six months. Filters from school (C) were mainly made of activated carbon with a thickness of 0.051 m. They had been used in toxic chemical lab for one year. Filters from office were mainly made of polyester fiber with a thickness of 0.010 m. They had been used in office for 3 months.

Ozone removal was also measured on new filters from shopping mall, school, and office buildings. It was assumed these new filters are identical with the used ones since they were purchased at the same time, at the same location, according to the filters donators.

2.3. Sample collection and analytical methods

Carbonyls upstream and downstream of the filter were collected in dinitrophenylhydrazine (DNPH) sampling tubes at a default flow

Table 1
Filter properties.

Filter	Material	Thickness	In field (Month)
Mall (A)	Polyester fiber	0.015 m	Mall (2.5)
Mall (B)	Polyester fiber	0.015 m	Mall (2.5)
School (A)	Glass fiber	0.051 m	General Building (6)
School (B)	Glass fiber	0.051 m	General Building (6)
School (C)	Activated carbon	0.051 m	Toxic Chemicals lab (12)
Office	Polyester fiber	0.010 m	Government Office (3)