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

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1 Introduction

Heating, Ventilating and Air Conditioning (HVAC) systems are widely used in certain parts of the world. Most of these recirculate a high fraction of their air (Weschler, 2009). Zhao et al. (2007) indicated the mean steady-state ozone removal efficiencies for loaded residential and commercial filters were 10% and 41%, respectively. In order to find out ozone removal rates and corresponding carbonyls generated by ozone reaction with HVAC filters in various building, i.e., shopping mall, school, and office building, one study was conducted in a small-scale environmental chamber. In addition, we examined dust properties such as organic carbon proportion and specific surface area on dusts adsorbed on filters along with ozone removal rates and carbonyls generation rate, and the relationship among dust properties, ozone removal rates, and carbonyls generation.

2 Materials/Methods

Laboratory experiments were conducted in a small stainless-steel chamber which was separated by a test filter. The chamber system was set up at 26℃, 60% relative humidity, and the input ozone concentration was 60 ppb. All air which entered the chamber was pre-filtered through silica gel, activated carbon, and HEPA in order to get clean air.

The air was pulled through a vacuum pump with fixed 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 (into the upstream 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 intervals of 10 seconds. Each experiment lasted 12 hours. The air flow rate of 25 L min^-1 through the filter was confirmed after each experiment finished with a bubble flow meter (Sensidyne, Model Gilibrator 2) at the outlet of the downstream chamber.

Air samples were collected by air pumps in dinitrophenylhydrazine (DNPH) sampling tubes, and 13 kinds of carbonyls (CARB Method 1004 DNPH Mix2) were then analyzed by GC/MS (Agilent 6890/MSD 5973). The minimum detection limit for individual carbonyl is 0.1 µg/m^3, but the results are reported to be the nearest 1 µg/m^3 in order to avoid a perception of higher confidence than warranted. Based on a limited number of duplicate samples performed by laboratory previously accuracy for carbonyls is +/-15%. The amount of organic carbon was analyzed by an TOC analyzer (Tekmar-Dohrmann Apollo 9000) and surface areas of dusts on filters were analyzed by specific surface area analyzer (BELSORP-mini II).

3 Results and Discussion

Some important properties of the tested HVAC filters are described in Table 1.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Material</th>
<th>Thickness</th>
<th>In Field (Month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mall(A)</td>
<td>polyester fiber</td>
<td>0.015 m</td>
<td>Mall (2.5)</td>
</tr>
<tr>
<td>Mall(B)</td>
<td>polyester fiber</td>
<td>0.015 m</td>
<td>Mall (2.5)</td>
</tr>
<tr>
<td>School(A)</td>
<td>glass fiber</td>
<td>0.058 m</td>
<td>General Building (6)</td>
</tr>
<tr>
<td>School(B)</td>
<td>activated carbon</td>
<td>0.058 m</td>
<td>Toxic Chemicals lab (12)</td>
</tr>
<tr>
<td>Office</td>
<td>polyester fiber</td>
<td>0.010 m</td>
<td>Government Office (3)</td>
</tr>
</tbody>
</table>

The ozone removal efficiencies on filters of
Mall (A), Mall (B), School (A), School (B), and Office range from 51 to 56%, 46 to 53%, 11 to 14%, 91 to 92%, and 8 to 9%, respectively. The concentrations of carbonyls (i.e., in this study including Acetaldehyde, Acetone, Acrolein, Benzaldehyde, 2-Butanone, Butyraldehyde, Crotonaldehyde, Formaldehyde, Methacrolein, Propionaldehyde, m-Tolualdehyde, Valeraldehyde, and Hexaldehyde) generated by ozone reactions on filters of Mall (A), Mall (B), School(A), School (B), and Office are 20.6 to 26.9 µg/m³, 17.2 to 24.0 µg/m³, 2.2 to 3.9 µg/m³, 83.7 to 89.5 µg/m³, and 1.4 to 1.7 µg/m³, respectively. In comparison, Hyttinen et al. (2006) observed the production of formaldehyde and Formic acid when ozone reacted with commercial HVAC filters, particularly at the beginning of ozone exposure.

The percentage of organic carbon in particles on filters of Mall (A), Mall (B), School (A), School (B), and Office are 22.0 to 31.6%, 19.3 to 26.6%, 7.7 to 11.4%, 88.0 to 90.9%, and 6.0 to 7.0%, respectively. Rogge et al. (1993) indicated the main source of organic carbon in air may include solvent or organic carbon from industrial processes, incomplete combustion of gasoline or diesel fuel from automobiles, organic compounds from the exhaust of plants, bio-aerosol, and cooking processes. Filters of Mall (A) were used in a mall in the middle of heavy traffic while filters of Mall (B) were used in suburb area, which may be the reason for a little higher organic carbon percentage on filters of Mall (A). Activated carbon filters of School (B) were used in a lab for toxic chemicals storage, which may lead to a much higher percentage of organic carbon (i.e. solvents and other organic compounds) on dusts adsorbed on filters.

The specific surface area on dusts adsorbed on filters of Mall (A), Mall (B), School (A), School (B), and Office are 0.59 to 0.62 m²/g, 0.58 to 0.63 m²/g, 21.59 to 25.86 m²/g, 489.4 to 545.5 m²/g, and 0.54 to 0.65 m²/g, respectively. The total pore volume of dusts adsorbed on filters and ozone removal efficiency or carbonyls generation on filters. In contrast, the results show highly positive correlation between ozone removal efficiency and the amount of organic carbon on filters (r²=0.960). Moreover, the carbonyls generations also have highly positive correlation with the amount of organic carbon on filters (r²=0.972). The results for mall (A), mall (B), school (A), school (B), and office building all show that formaldehyde is the dominant carbonyl, followed by acetaldehyde.

4 Conclusions
Past research indicate that filter material, filter used time, filter thickness, and the surrounding air quality of filter, may affect ozone removal efficiency. In this study, the results show that there is a well-defined positive correlation between ozone removal efficiency and carbonyls generation on filters, as well as a positive correlation among the amount of organic carbon on filters, ozone removal efficiency and carbonyls generations. No significant correlation was found between surface areas of dusts on filters and ozone removal efficiency or carbonyls generation. Thus, it appears that the chemical compositions of dusts on filters may have greater influence with ozone removal efficiency and carbonyls generation on filters than physical properties of dusts on filters.

5 References

6 Acknowledgements
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