EXAMINATION OF THE PHYSICAL AND CHEMICAL NATURE OF USED VENTILATION FILTERS AND COLLECTED PARTICULATE MATTER

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ABSTRACT
Maintenance workers expressed concern of a potential health hazard due to a strong odor from used ventilation filters during routine maintenance at a research facility. This prompted a thorough examination of the physical and chemical nature of the filters and collected particulate matter. Light and electron microscopy indicated a predominance of opaque small particles, mostly in the submicrometer range. Many were agglomerations of smaller, roughly spherical subunits, consistent with combustion aerosol. Headspace samples of filter portions were analyzed by gas chromatography-mass spectroscopy (GC-MS). Numerous volatile organic compounds were found on all samples at sub-ppm concentrations. Possible odor sources are: combustion aerosol containing adsorbed vapors, organics normally present in ambient environments concentrating on the particles, and/or microbial growth. The combined approach of GC-MS/microscopic examination proved useful in determining the vapor and solid collection history of ventilation filters. The concentrations of toxic substances were below levels at which adverse effects would be expected.

INDEX TERMS
Ventilation Filters, Health Effects, Volatile Organic Compounds, Particulate Matter

INTRODUCTION
Maintenance workers at a research facility change the ventilation filters in the air-handling unit (AHU) on a regular schedule. During the latest filter change-out, the maintenance workers noticed a strong odor emitting from the used medium efficiency filters. A request was made to investigate the odor to determine if there were any potential health effects to the maintenance workers and/or building occupants from the material collected on the used ventilation filters.

It has been demonstrated that ventilation filters can collect fungal spores as well as bacteria (Jankowska, Reponen, Willeke, et al., 2000; Mortiz, Peters, Nipko et al., 2001). Jankowska et al. tested samples from medium and fine efficiency filters with *P. brevicompactum* and *P. melinni*. The medium efficiency filter collected 69% of the *P. brevicompactum* and 73% of the *P. melinni*, while the higher efficiency filter collected 98% and 99.3% respectively. Other studies have shown that both fungi and bacteria can not only survive on ventilation filters but also can grow and proliferate. (Mortiz, Schleibinger and Ruden, 1998; Simmons and Crow, 1995; Simmons, Price, Noble et al., 1997). Fungi growing on air filters can release such

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metabolite volatiles as acetone and a carbonyl sulfide-like compound (Ahearn, Crow, Simmons et al., 1997). Other volatile organic compounds produced by fungi living on fiberglass include 2-ethyl hexanol, cyclohexane, and benzene (Ezeonu, Price, Simmons, et. al, 1994). Schleibinger et al. carried out field measurements of the air before and after the prefilters and main filters of two large ventilation systems (Schleibinger, Wurm, Moritz et al., 1997). Since they found the concentration of volatile organic compounds (VOCs) increased after the filters especially those made from fiberglass, they concluded microbial production of VOCs in HVAC systems was possible.

Since there is evidence that bacteria can survive on ventilation filters under certain conditions and produce VOCs, a study was conducted to determine the source of the odors and if they could pose any adverse health effects either to the maintenance workers or the occupants of the building. Gas chromatography was used to determine the type and concentration of any VOCs being emitted from the used filters. Microscopy was used to ascertain the nature of the collected material on the used filters and if microorganisms could be the source of any VOCs found by gas chromatography.

METHODS

The AHU contained a bank of 32 filters (8 filters in 4 rows). The filters were Purolator Defiant Filtration Media Model D95124412 K. Each filter consisted of 12 individual filter bags. Ten filters were selected for analysis. These filters were immediately sealed inside an airtight box after being removed from the AHU. In each filter, the middle bags were selected for study. Each filter was divided into two pieces. One piece was used for microscopic inspection and the other piece was used for headspace analysis.

licroscopic analysis

amples of prefilters and bag filters were analyzed using both light and scanning electron microscopy. For light microscopy, samples were mounted in refractive index liquid and viewed with a Zeiss polarized light microscope. For electron microscopy, a portion of the filter was cut, gold/palladium coated, and examined directly with a Joel JSM 6400 microscope. Additionally, approximately 10 cm^2 portions of filters were cut out and placed in 50 mL centrifuge vials. Freshly filtered water was added. The vials were sonicated and the resulting hydrosols were filtered through either polycarbonate or cellulose ester filters. The polycarbonate filters were metal coated and examined by scanning electron microscope and the cellulose ester filters were acetone cleared for light microscopy analysis.

Gas Chromatographic Analysis

Approximately 130 cm^2 of each of the used filters and cardboard prefilter frame was placed in a 650 mL Pyrex bottle with a plastic lid after one month inside the airtight box. The lid was outfitted with a sampling adapter to facilitate the removal of a 400 mL sample into a silonite-coated mini-canister for analysis by gas chromatography. In addition to the used filters, a sample of new filter media was used as a control. One bottle was left empty as a headspace blank. Air samples were taken in the AHU to help identify the source of any contaminants found in the headspace samples. The air was sampled from: upstream of the prefilters, downstream of the prefilters, upstream of the final filters, and downstream of the final filters. Air samples were taken before and after the filters were changed. The samples were collected in 400 mL silonite-coated mini-canisters. A 0.39 cm I.D. by 61 cm stainless steel probe was attached to the mini-canister to collect samples from inside the AHU while it was in operation.

Gas chromatography was used to analyze the air and headspace samples for VOCs. The analysis system consisted of an Entech Model 7100 preconcentrator and an Agilent Technologies Model 5890 gas chromatograph with a Model 5972 mass selective detector. The 7100 preconcentrator was programmed with EPA TO-15 canister analysis with Microscale Purge and Trap Water Management. The air sample was trapped cryogenically on glass beads in the first module to concentrate the VOCs. The module was then heated and helium transferred the VOCs to the second module containing Tenax. In the second module, the CO_2 was purged. After the second module, the sample was cryo-focused in the third module allowing a rapid injection of the VOCs onto the HP-5MS 30 m × 0.32 mm × 0.25 µm column. The gas chromatograph was programmed with an initial oven temperature of -30°C. This temperature was held for 2 minutes. The oven temperature was then ramped at 8°C/min until a temperature of 220°C was reached. The oven temperature was then held constant for 5 minutes. The total run time for a sample was approximately 28 minutes.

RESULTS AND DISCUSSION

Microscopy

The filtering element of the prefilter consisted of synthetic fiber. A wire mesh inside a cardboard framework supported the filter. Visual inspection of the framework showed evidence of water exposure and a pattern of dark, generally round points of contamination. Fungal growth was suspected and confirmed. Particles observed within the filtering element of the prefilters included trichomes, fungal spores, pollen grains, insect fragments and various mineral fragments (Figure 1).

Figure 1. SEM Image of Filter Fibers.

Upon removal of the prefilters from the system, settled dust deposits were noted on the coils located immediately downstream from the filters. This dust was collected and found by light microscopy to consist mostly of trichomes (Figure 2). The large size of these common outdoor particles (hundreds of micrometers) suggests that they traveled around rather than through the prefilters.

The bag filters were found by microscopy examination to be composed of several layers of synthetic fiber. The unexposed filter layers were white and light blue. The exposed filters were black through the full depth of the filter suggesting exposure to fine particles (Figure 3). Light microscopy confirmed that the particles collected within the bag filter were generally smaller than those observed in the prefilter. Particle types included fungal spores, starch grains and a predominance of opaque material. Figures 4 and 5 provide a closer look at these small particles. Although conclusive identification is difficult with such particles, the geometry of many of the particles (agglomerations of roughly spherical sub-units) is consistent with combustion aerosol.

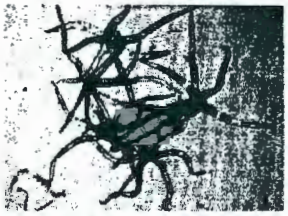

Figure 2. Trichomes observed on the coil unit downstream from the prefilters.

Figure 3. Cross-sectional view of un-exposed (top) and exposed (bottom) bag filters. Sampling was top to bottom. Note chromatic evidence of penetration through full depth of the filter.

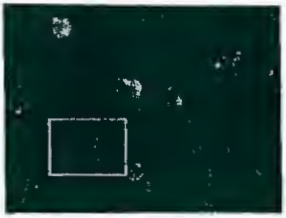

Figure 4. Scanning electron microscope image of particles isolated from bag filter.

Figure 5. Close-up view of the boxed area of Figure 4. Note agglomeration of roughly spherical sub-units suggestive of combustion aerosol.

Gas Chromatographic Analysis

Table 1. Head Space Concentration Results in ppbv

Compound	Clean Final Filter	Used Final Filter	Used Prefilter Cardboard	Used Prefilter
Acetone	65	275	210	564
[2-methylpropanal]	N.D.[A]	65	33	N.D.[A]
[2-butenal]	20	104	43	64
[2,3-butanedione]	N.D.[A]	167	51	127
Benzene	N.D.[A]	2.4	1.7	1.5
Pentanal	N.D.[A]	8.5	N.D.[A]	N.D.[A]
1-butanol	N.D.[A]	14	3.7	10
[C6 Aldehyde/Ketone]	N.D.[A]	8.6	14	202
Toluene	N.D.[A]	3.0	2.2	6.4
Octane	N.D.[A]	1.5	8.1	21
Hexanal	N.D.[A]	75	N.D.[A]	N.D.[A]
Ethylbenzene	N.D.[A]	80	6.2	N.D.[A]
m- & p-Xylene	N.D.[A]	56	4.7	4.2
o-Xylene	N.D.[A]	32	2.9	N.D.[A]
Cyclohexanone	N.D.[A]	1.5	N.D.[A]	N.D.[A]
[Heptanal]	N.D.[A]	65	N.D.[A]	N.D.[A]

[A]N.D. = Not Detected [] = tentative identification

The compounds listed in Table 1 are 16 of the most prevalent compounds found in all of the used filter headspace samples. Thus, these compounds were selected as target compounds for GC-MS identification and quantification. The results indicate the clean filter media does off-gas low levels of acetone and 2-butenal. None of the other 14 target compounds were found in the clean filter media sample. The used filter media and cardboard contained a significant increase in the acetone and 2-butenal concentrations (>300% and >200% respectively). Therefore, the material collected on the filters was either emitting these compounds or serving to concentrate these compounds on the filter surface. The differences in concentrations between the prefilters and final filters may be due to differences in the amount and type of materials collected on each filter. The prefilter and final filter samples also show compounds consistent with exhaust particles. Benzene, toluene, octane, ethylbenzene and the xylenes are very typical of vehicle exhaust. This further supports the microscopic results discussed earlier.

Table 2. Air Sampling Concentration Results in ppbv

Time	Sampling Location	Compound				
		Benzene[A]	Toluene[B]	Ethylbenzene[B]	m- & p-Xylene[B]	o-Xylene[B]
Before Filter Change	Before Prefilter	0.6	0.8	14	9.9	1.4
	After Prefilter	0.3	0.8	0.9	1.2	0.3
	Before Final	0.7	1.2	3.6	0.2	0.3
	After Final	0.4	0.8	3.1	0.8	0.3
After Filter Change	Before Prefilter	1.8	2.0	17	5.9	6.6
	After Prefilter	1.9	2.2	17	6.9	7.7
	Before Final	1.7	1.9	18	7.4	7.8
	After Final	1.6	1.7	21	9.9	8.7
One Month After Change	Before Prefilter	1.5	8.7	18	11	8.6
	After Prefilter	0.7	7.9	10	5.5	5.1
	Before Final	1.5	15	21	11	10
	After Final	1.5	8.7	18	11	9.3

[A]NIOSH Recommended Exposure Limit (REL) = 100 ppb [B]NIOSH REL = 100 ppm

Some air sampling results are contained in Table 2. Samples, taken before the filters were changed, indicate that the concentrations of contaminants coming into the ventilation system were reduced when they passed through the prefilters. After the filter change, the concentrations remained relatively stable upstream of the prefilter to downstream of the final filter. Samples taken one month after the filter change started to show a decrease in concentration downstream of the prefilters. This decrease was smaller in magnitude yet similar to that observed before the filters were changed. This supports the conclusions reached from the filter headspace samples the filters were adsorbing and concentrating the VOCs. The second notable observation is that some of the contaminants increased in concentration between the prefilter and the final filter. The only source of this increase could be the fan, which is situated between the prefilter and final filter. To confirm this, additional air samples were taken in the fan room and headspace samples of material from the fan belt were analyzed. These samples confirm some VOCs are being emitted from the fan.

Given the vapor adsorption properties of carbonatious material, it is suspected that these filters are acting like a large vapor collection bed. After months of concentrating organic vapor, odor is predictable. The source of the vapor is probably diverse. First, this sort of particulate matter, as emitted as exhaust from vehicles, will contain adsorbed vapors from the

combustion process. Additionally, such a carbon bed could concentrate organics that are normally present in ambient environments. Vapors from microbial growth are of particular interest here, since microscopic examination of system prefilters showed extensive fungal contamination both in collected dust as well as on the filter framework.

CONCLUSION AND IMPLICATIONS

No evidence of hazardous concentrations of VOCs was found to be released by the filters. All concentrations were in the sub-ppm range and well below the NIOSH Recommended Exposure Limits. The filters should pose no health hazard to either the maintenance workers or building occupants. The strong odors from the filters may be caused by compounds, which cannot be detected using GC-MS. Concentrations were generally below reported odor threshold values. The study indicates that shortening the filter change-out schedule may reduce the maintenance worker complaints of odor from the filters. Further research is needed to determine the optimum schedule and identify the exact compounds causing the odors.

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DISCLAIMER

Mention of a specific product does not constitute endorsement by the National Institute for Occupational Safety and Health or the U.S. Environmental Protection Agency.

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