OZONE REMOVAL BY CHARCOAL FILTERS AFTER CONTINUOUS EXTENSIVE USE (5 TO 8 YEARS)

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ABSTRACT

This paper presents ozone removal efficiencies, measured over an extended period of time, in three different settings: a test plenum, an air handler providing outdoor air to a Class 100 cleanroom, and a plenum downstream of an air handler providing outside air to a second, smaller Class 100 cleanroom. In each of these settings, the initial ozone-removal efficiencies were comparable. After 8 years of service, the charcoal filters servicing the first cleanroom were removing about 60% of the ozone in the airstream. After 7 years of service, the charcoal filters servicing the second cleanroom were removing 70% of the ozone in the airstream. After 5 years of continuous operation, the charcoal filters in the test plenum were removing more than 90% of the ozone in the airstream. These results indicate that adequately sized charcoal filters have very long service-lives for ozone removal, provided their active sites are not compromised by accumulated sub-micron particles.

INTRODUCTION

Ozone has both acute and chronic health effects, and contributes to the degradation of materials [1]. Indoor environments offer some protection from outdoor ozone, but the protection decreases with increasing air exchange rates. Charcoal filters, installed in the HVAC system, have been used as a means to remove ozone from ventilation air. Unfortunately, there is only a small amount of information concerning charcoal's ozone removal efficiency, service life, and the factors that influence both. Shair [2] examined the ozone removal efficiencies of charcoal filters located in an air handler servicing a building on a California university campus. At the end of the first, second and third years of operation, the measured removal efficiencies were 95%, 80%, and 50%, respectively. However, these filters were only used intermittently and were not protected from soiling (by sub-micron particles). Kelly and Kinkead [3] have examined the ability of chemically treated filters to remove ozone from an airstream. During an 80-hour test, the upstream O_3 concentration averaged 118 ppb while the downstream concentration was close to zero. Although there have been a number of excellent studies examining the sorption of organic gases and water vapor on charcoal, their findings do not bear directly on the removal of ozone by charcoal filters. Sorption is of minor importance in the latter process, which is dominated by chemical interactions between ozone and dangling carbon bonds on the charcoal surface [4, 5 and references therein].

In May 1990, we initiated an evaluation of commercial charcoal filters for the removal of ozone. Preliminary results, obtained in a test plenum and in an air handler servicing a Class 100 cleanroom (Cleanroom #1), were presented in 1993 [4]. In a 1994 paper [5] we updated the earlier results and added results from a third location – another Class 100 cleanroom (Cleanroom #2). At that point the filters in the test plenum and Cleanroom #1 had been in service 37 months, while those in Cleanroom #2 had been in service 24 months. This paper further updates those results, presenting data obtained after 8 years of service (Cleanroom #1), 7 years of service (Cleanroom #2) and 5 years of operation (test plenum).

METHODS

Ozone concentrations were measured using ultraviolet photometric analyzers (254 nm). To evaluate filter removal efficiencies, ozone concentrations were measured immediately upstream and downstream of the filters. In the phase of the study under discussion, this was accomplished using a single instrument interfaced to a computer and a three port solenoid valve. The latter alternated sampling between upstream and downstream on a 7.5-minute cycle. At the start of each upstream or downstream cycle, the sampling line was purged for 2.5 minutes; O_3 values were read at 30-second intervals for the next 5 minutes; the average of these 10 readings was then recorded.

The charcoal filters examined in this study were configured as "half" cells, each containing six carbon panels arranged in a zig-zag configuration within the 24" x 12" housing. A single panel holds 3.4 kg (7.5 lb) of virgin coconut shell activated carbon (4 x 8 mesh rated at 60% wt carbon tetrachloride activity [6]). Hence, each "half" cell contains 20 kg (45 lb) of activated carbon.

Details concerning the test plenum, Cleanroom #1, and Cleanroom #2 have been previously presented [5]. In brief, the test plenum contains one "half" cell, and the average airflow through the plenum is 0.28 m^3/s (600 cfm). Upstream of the charcoal filters is an 85% filter (ASHRAE dust spot rating) and upstream of the 85% filter is a 30% filter. The air-handling unit for Cleanroom #1 contains 24 charcoal "half" cells. The airflow through the filter bank is 10.2 m^3/s (21,700 cfm), and consists *only* of outside air. Filters with ASHRAE dust-spot ratings of 30% are installed upstream of the carbon filters, and filters with a rating of 85% are installed downstream of the carbon filters. The ductwork that delivers air to Cleanroom #2 contains 2 charcoal "half" cells. The airflow through the filter bank is 1.4 m^3/s (3000 cfm). Filters with ASHRAE dust-spot ratings of 30%, followed by filters with a rating of 85% and the cooling coils are located upstream of the carbon filters.

RESULTS

The ozone removal efficiencies are calculated as (1-[D/U]), where D is the downstream ozone concentration and U is the upstream ozone concentration. Only intervals when the upstream concentrations are not changing significantly (less than 10% change from previous set of readings) have been used in obtaining the results.

Cleanroom #1

The charcoal filters servicing Cleanroom #1 were installed on July 20, 1990. Figure 1 shows ozone removal efficiencies measured for these filters more than eight years later -- August 1998. Each plotted point corresponds to a 15-minute upstream/downstream measurement, obtained as described in the *Methods* section. The points tend to lie in a band between 55% and 65%, with a median value of 59%. However, on several days the removal efficiency temporarily drops below 40% (e.g., August 10-11, 18 and 23). These periods will be addressed in the *Discussion* section.

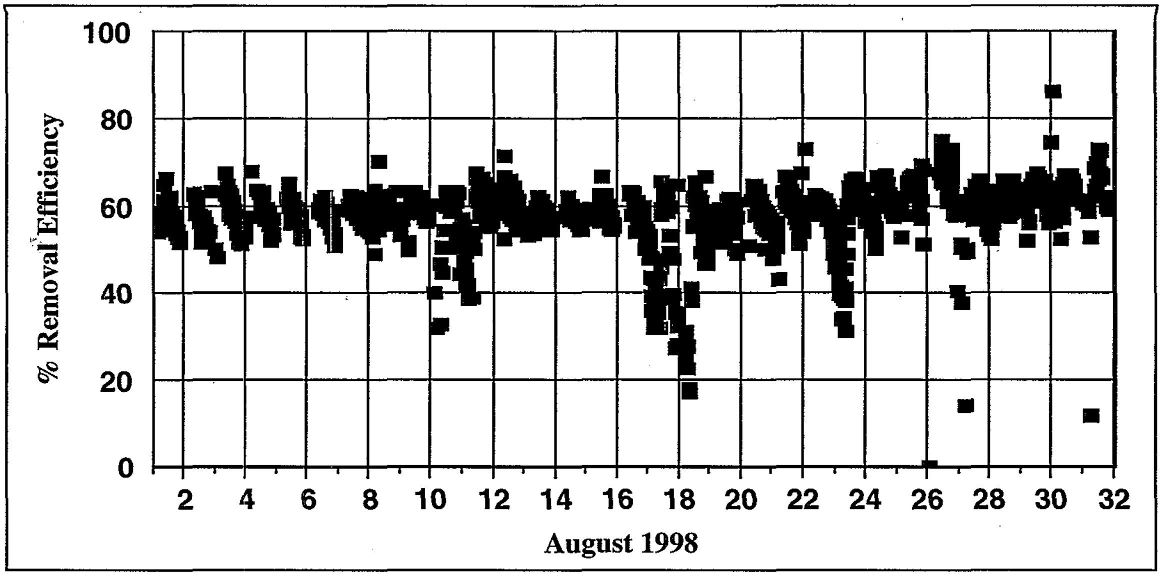

Figure 1. Ozone removal efficiencies measured during August 1998 for charcoal filters servicing Cleanroom #1. Filters had been in continuous service for more than 8 years.

Figure 2 shows ozone removal efficiencies versus upstream ozone concentrations for the data plotted in Figure 1. It is apparent that the removal efficiency is independent of the ozone concentration for upstream ozone values in the range of 10 to 135 ppb.

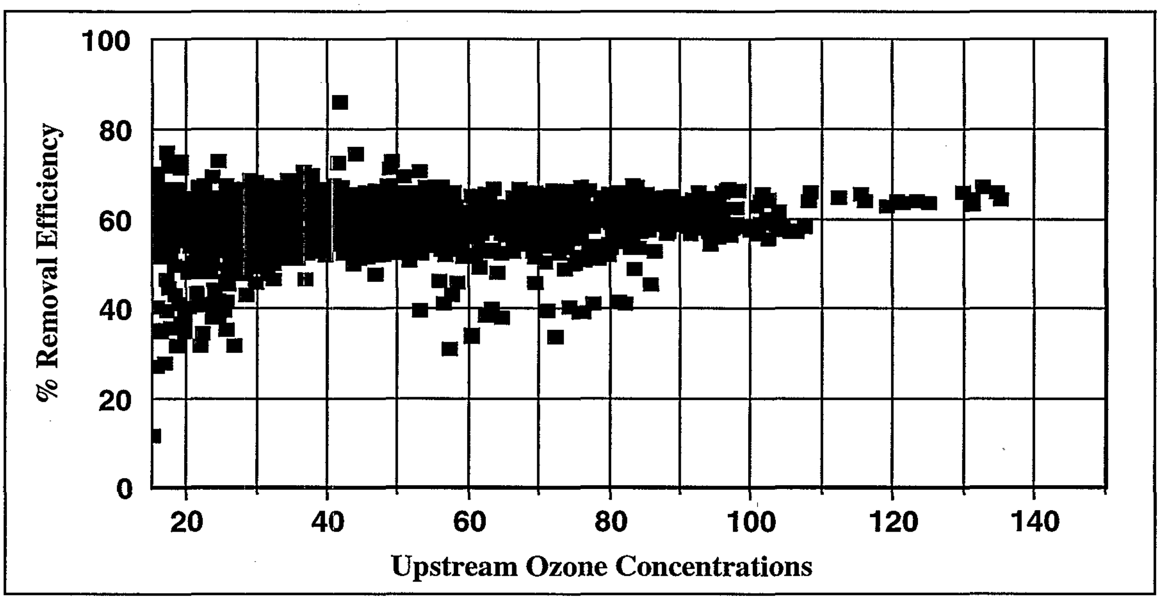

Figure 2. Ozone removal efficiencies versus upstream ozone concentration (August 1998) for Cleanroom #1 charcoal filters. Filters had been in continuous service for more than 8 years.

Cleanroom #2

The charcoal filters servicing Cleanroom #2 were installed in September 1991. Figure 3 shows their ozone removal efficiencies seven years later -- September 1998. The plotted points (corresponding to 15-minute upstream/downstream measurements) tend to lie in a band between 65% and 75%, with a median value of 69%. However, on several days the removal efficiency temporarily drops below 55% (e.g., September 9 and 10).

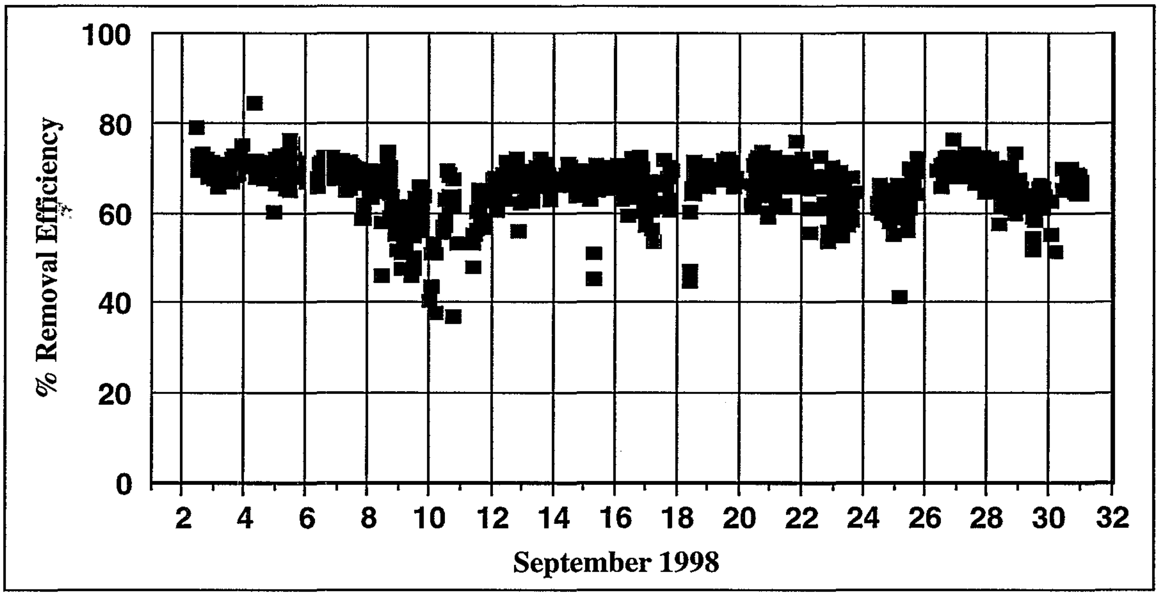

Figure 3. Ozone removal efficiencies measured during September 1998 for charcoal filters servicing Cleanroom #2. Filters had been in continuous service for more than 7 years.

Figure 4 shows ozone removal efficiencies versus upstream ozone concentrations for the data plotted in Figure 3. It is apparent that the removal efficiency is independent of the ozone concentration for upstream ozone values in the range of 10 to 80 ppb.

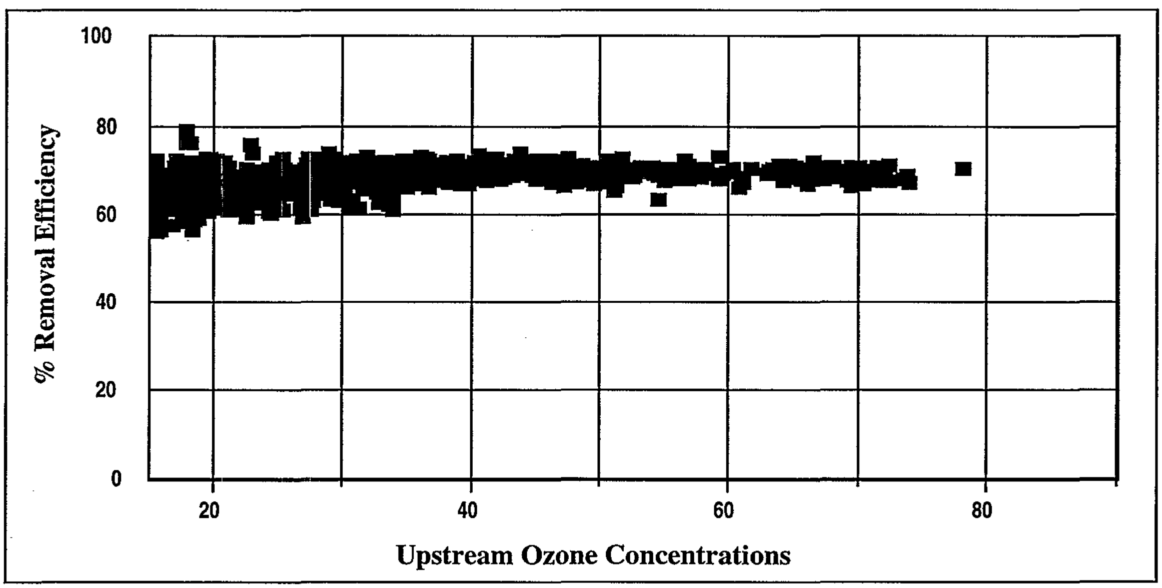

Figure 4. Ozone removal efficiencies versus upstream ozone concentration (Sept 1998) for Cleanroom #2 charcoal filters. Filters had been in continuous service for more than 7 years.

Test Plenum

Charcoal filters were installed in the test plenum in May 1990. The plenum was then operated continuously for more than 5 years. The ozone removal efficiency recorded at the end of this five-year period was 90%. No additional measurements have been made on the filters in the test plenum.

DISCUSSION

Table 1 presents data obtained, since the initiation of this study, on the ozone-removal efficiencies of the charcoal filters in the test plenum and servicing Cleanrooms #1 and #2. It also contains information on the airflow per unit weight of charcoal, and summarizes the location of the charcoal filters relative to the particulate filters for each application (see *Methods* section). Due to less efficient upstream particulate filtration, the filters servicing Cleanroom #1 were exposed to more sub-micron particles than were the filters servicing Cleanroom #2 or contained in the plenum. As a consequence, the removal-efficiency decreased more rapidly in the Cleanroom #1 application -- after slightly more than 3 years the removal-efficiency was down to 60% in Cleanroom #1, while after the same length of service the efficiency was 90% in the test plenum and 95% for Cleanroom #2. Interestingly, the removal-efficiency of the filters servicing Cleanroom #1 did not change significantly from the three-year mark through the 8 year mark. As illustrated in Figures 1 and 2, these filters were still removing about 60% of the ozone in the airstream after 8 years of service. As the time-in-service for the filters in the plenum and Cleanroom #2 increased from 3 years to 5 years, there was little change in their removal efficiencies – still in the range of 90%. However, as the time-in-service for the Cleanroom #2 filters extended from 5 years to 7 years, the removal-efficiency decreased from 92% to 70%. This suggests that, even with the protection of 85% particulate filters, soiling by sub-micron particles was beginning to compromise the sites responsible for ozone's removal.

Table 1. Summary of configurations and removal efficiencies for charcoal filters.

	Airflow/ Weight of Charcoal (cfm/lb)	Position of Charcoal Filters	Ozone Removal Efficiencies (%)						
			0 yrs	1.1 yrs	2 yrs	3.1 yrs	5 yrs	7 yrs	8 yrs
Test Plenum	13.3	30%,85%, charcoal	95	–	92	90	90	–	–
Cleanroom #1	20.1	30%, charcoal, 85%, cooling coils	85	85	–	60	60	–	60
Cleanroom #2	16.7	30%, 85%, cooling coils, charcoal	95	–	95	95	92	70	–

In both Figures 1 and 3 there are periods when the ozone removal efficiency dips significantly below the median value. At least a partial explanation for these dips appears to be the occurrence of high relative humidity in the air passing through the charcoal filters. Figure 5 shows mean visibility and precipitation data from a weather station located about 10 miles from the site where the charcoal filters were in service. Note that the periods when the visibility decreases in Figure 5 tend to correlate with periods of decreased ozone removal efficiencies in Figure 1. Decreases in mean visibility can be used as a surrogate for periods of high relative humidity. When the relative humidity rises above the deliquescence point of the salts that constitute the airborne sub-micron particles, these particles take on moisture, grow in size, and scatter more light. Presumably, at high relative humidities water molecules occupy sites that might otherwise interact with ozone. Whatever the mechanism, it is reversible, as evidenced by the fact that the "normal" ozone removal efficiency returns when the visibility improves (relative humidity decreases).

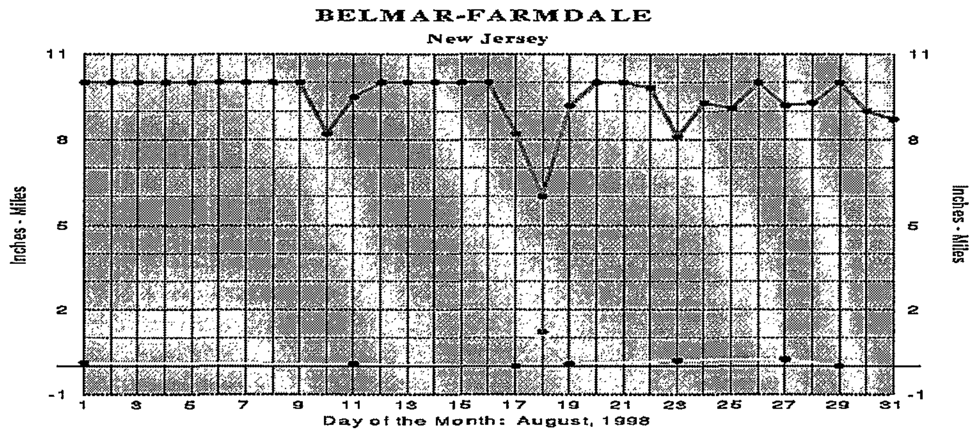

Figure 5. Mean visibility (top line -- miles) and precipitation (bottom line -- inches).

In areas with severe photochemical smog, charcoal filters offer significant protection for occupants, equipment and cultural artifacts in mechanically ventilated buildings. Charcoal filters can also limit the indoor occurrence of ozone-driven chemical reactions that produce undesirable products [7]. Due in part to their high initial cost, charcoal filters are underutilized for such purposes. However, as indicated in Table 1, their service life for ozone removal is significantly greater than five years if they are adequately protected from soiling. Hence, their annualized cost is often significantly less than the money saved as a consequence of their use.

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