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OZONE REACTION WITH BUILDING MATERIALS: EFFECTS OF DIURNAL VARIATION AND ENVIRONMENTAL CONDITIONS

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INTRODUCTION

Ozone exposure is associated with adverse health effects such as asthma and mortality risk. Ozone reacts readily with indoor surfaces, resulting in reduced ozone exposures but also elevated concentrations of reaction byproducts in the occupied spaces. Reaction byproducts such as formaldehyde might adversely affect the health and well-being of building occupants (Weschler, 2006). Previous studies (Gall et al., 2013; Cros et al., 2012) have found that ozone-surface reaction rates can vary with the material surface type and with airflow conditions adjacent to surfaces. Little information is available on how the diurnal pattern of ambient ozone concentrations might influence ozone reaction with indoor surfaces. Also, most research on ozone-surface interactions has been undertaken at fixed temperature and relative humidity levels. The present study investigates ozone-surface reactions for common indoor finishing materials in the presence of a systematic diurnal variation in ozone exposure level. The test data will be used for elucidating the effects of environmental conditions (temperature, humidity, and ozone concentration) on the ozone reaction dynamics in buildings.

METHODS

Experiments were conducted in a 10.5-liter environmental chamber. The chamber is maintained at constant user-specified values of temperature and relative humidity. The chamber is continuously ventilated with air containing a controlled amount of ozone. Using this system, experiments were performed over a range of air temperature (22-28 °C) and relative humidity (RH, 25-75%). Two common building materials were tested: a perlite-based ceiling tile and painted drywall (with mold-resistant paint). The tested materials were new and stored in sealed packages until the beginning of each experiment. An experiment was initiated by flushing the empty chamber with ozone for a day to remove potential reactive sites on chamber surfaces. Each material sample (one side exposed with the edges sealed and the exposed area of 225 cm^2) was conditioned in the environmental chamber for a minimum of two days prior to testing. The conditioned sample was then placed in the middle of the clean chamber and exposed to air with ozone for 8 hours followed by ozone-free air for 16 hours. This exposure pattern was repeated for a second two-day period.

Each experiment included measurements of air temperature, humidity, and ozone concentration. The chamber air-exchange rate was controlled at 10 h^{-1} using taper-tube flow meters, while absorbance-based analyzers continuously measured the ozone level in the outlet air. For each specified set of temperature and humidity levels, ozone deposition velocity was calculated using the following dynamic mass balance model (Equation 1).

$$\frac{dC}{dt} = \lambda_v (C_{out} - C) - v_d \frac{A}{V} C \quad (1)$$

Here, C = ozone concentration in the chamber (ppb_v), C_{out} = supply ozone concentration (ppb_v), v_d = ozone deposition velocity (cm/s), λ_v = air exchange rate (s^{-1}), A = material surface area exposed to ozone (cm^2), V = volume of the chamber (cm^3).

RESULTS AND DISCUSSION

Figures 1a and 1b show the time-varying ozone concentration profile and the corresponding dynamic deposition velocity observe with the new ceiling tile for two consecutive days. Figure 1a indicates that ozone concentration in the chamber gradually increases as the surface was exposed to ozone for the first and second day. The chemical reaction of ozone with the surface mainly occurs during the ozone exposure, while the adsorption/desorption of ozone by the material surface is relatively negligible, given the almost zero ozone concentration during the 16-h ozone-free air supply period. Figure 1b reveals that the ozone deposition velocity is highest when a surface was initially exposed to ozone; however, the deposition rate slows down as ozone oxidizes the reactive sites (unsaturated carbon bonds) of the surface material. This "surface-aging" phenomenon was larger on the first day than on the second.

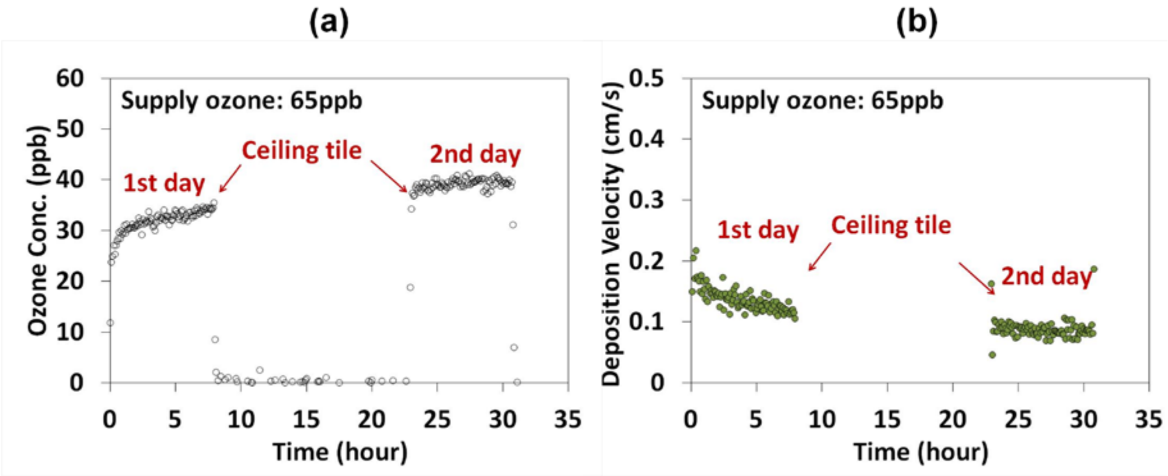

Figure 1. Ozone concentration profile (Figure 1a) observed with a ceiling tile (T = 28 ˚C, RH = 50%) and the dynamic deposition velocity calculated using Eq. (1) (Figure 1b)

Table 1 summarizes ozone deposition velocities observed at two different temperature (22 ˚C and 28˚C) and three humidity levels (25%, 50%, 75% *RH*). Table 1 indicates that ozone deposition velocity for the ceiling tile tended to be higher with increasing humidity. The highest ozone deposition velocity (0.24 cm/s) was measured at the highest humidity level (75 % *RH*). On the other hand, no clear effect of temperature on ozone deposition velocities was observed for the ceiling tile and painted drywall. The ozone deposition velocity varied with the building material, implying that the tendency for a surface to react with ozone is a strong function of indoor surface material type.

In general, the ozone deposition velocities found in this study for ceiling tile and painted drywall are higher than or similar to the values reported in previous studies (Gall et al., 2013; Cros et al., 2012). Overall, the results suggest that surface type and humidity level have measurable influences on ozone deposition velocity, while temperature (between 22 ˚C and 28˚C) has minimal effects on ozone-surface reaction rates.

Table 1. Summary of deposition velocity observed for the first and second days

Material (Conditions)	Average deposition velocity (cm/s), (±SD)*	
	Day 1	Day 2
New ceiling tile (28 ˚C, 50% RH)	0.15 (±0.02)	0.09 (±0.01)
New ceiling tile (22 ˚C, 50% RH)	0.15 (±0.02)	0.12 (±0.02)
New ceiling tile (22 ˚C, 25% RH)	0.14 (±0.02)	0.12 (±0.02)
New ceiling tile (22 ˚C, 75% RH)	0.24 (±0.03)	0.21 (±0.02)
New painted drywall (28 ˚C, 50% RH)	0.20 (±0.02)	0.18 (±0.01)
New painted drywall (22 ˚C, 50% RH)	0.18 (±0.03)	0.19 (±0.02)

*SD = standard deviation for the 8-h ozone exposure.

CONCLUSIONS

The present study investigates ozone-surface interactions with realistic temporal patterns of ozone concentrations. The experiment results show that the rates of ozone removal due to ozone-surface reactions depend on the ozone concentration profile, such that for the new ceiling tile the ozone uptake rate declined on the second day of exposure relative to the first. Material surface type and humidity level have measurable influences on ozone deposition velocity, while temperature (between 22 ˚C and 28˚C) has a minimal effect on the ozone-surface reaction rate. The study results advance our knowledge and understanding of ozone-initiated indoor chemistry, an important aspect of indoor environmental quality.

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REFERENCES

Cros, C. J., Morrison, G. C., Siegel, J. A. et al. (2012) Long-term performance of passive materials for removal of ozone from indoor air. *Indoor Air*, ***22***, 43-53.

Gall, E., Darling, E., Siegel, J.A. et al. (2013) Evaluation of three common green building materials for ozone removal, and primary and secondary emissions of aldehydes. *Atmospheric Environment*, **77**, 910-918.

Weschler, C. J. (2006) Ozone's impact on public health: contributions from indoor exposures to ozone and products of ozone-initiated chemistry. *Environmental Health Perspectives*, ***114***, 1489-1496.