Effect of the Airocide APS-200 PM 2.5 Photocatalytic Oxidation (PCO) Unit on PM $_{2.5}$

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Abstract

This study explored the effect of the Airocide APS-200 PM 2.5 Unit on the degradation of PM $_{2.5}$ to establish the efficacy of the unit relative to its use as an indoor air-cleaning device. A 1,000 ft^3 room was selected as the test location because it is analogous to a common Hotel Room or Living Space. A TSI Dust Trak II Monitor was utilized to determine PM $_{2.5}$ concentrations in milligrams per cubic meter (mg/m3) for the selected room. Approximately 134 cm^3 of Tidy Cat litter was distributed onto the carpet, and then vacuumed using a Bissell Vacuum Cleaner to obtain an initial concentration of .061 mg/m^3 of PM $_{2.5}$. Samples collections were obtained over a 1 hour period. Samples were taken in one second intervals, or a total of 3,600 times, and the average of each sampling event was utilized. Data revealed that the Airocide APS-200 PM 2.5 PCO Air Cleaning Unit was effective in the removal of PM $_{2.5}$. Data indicates that degradation of PM $_{2.5}$ to below the EPA/ARB/WHO exposure limit of .012 mg/m^3 occurred in approximately 48 hours. The operational principle behind the TiO_2 PCO reaction mechanism is generally non-specific with regards to the substances affected by the PCO process, therefore, it is reasonable to extrapolate that the similar results would be expected if the Airocide Unit encountered other categories of PM, in addition to volatile organic compounds (VOC) and microbes. In conclusion, this study revealed thatthe Airocide APS-200 PM 2.5 PCO Unit had a positive effect on the reduction of PM $_{2.5}$ and would be effective in the control of PM $_{2.5}$ in the indoor environment.

Introduction

Fujishima and Honda discovered the photocatalytic splitting of water on TiO_2 electrodes in 1972[1]. This event initiated the beginning of a new era in heterogeneous photocatalysis where photo-induced molecular transformations or reactions occur on the surface of the catalyst. One of the primary mechanisms of the reactions involves the production of hydroxl radicals, which subsequently undergo “oxidation” reactions with other atoms and/or compounds. Subsequently, the term photocatalytic oxidation or PCO has been developed to generally describe the type of reactions that are occurring on the TiO_2 surface. Since that time extensive research has been performed in understanding the fundamental processes and in enhancing the photocatalytic efficiency of TiO_2[2]. Many studies have been related to energy renewal and storage[3-7]. In more recent years, the application of PCO has been directed towards environmental cleanup. This has been inspired by the potential application of TiO_2-based photocatalysis for the total destruction of organic compounds in polluted air and wastewaters[8-9]. Numerous studies have evaluated PCO as a promising tool for the improvement of indoor air quality and energy reduction. An estimated 10% of the energy consumed by commercial buildings is utilized in the conditioning of ventilation air[10-11]. Therefore, a significant reduction in energy usage could be obtained by tightening buildings and reducing ventilation rates; however, these strategies would require the parallel implementation of measures to maintain appropriate indoor air quality, including source control measures and the operation of advanced air-cleaning technologies. It has been estimated that achieving a 50% reduction in outdoor air ventilation in a typical building in the United States would require a pollutant removal efficiency of 15-20% in order to prevent increased occupant exposure to volatile organic compounds (VOCs)[12-13]. PCO is a promising technology for indoor air purification[14-16]. PCO can decompose a broad spectrum of VOCs containing multiple chemical functionalities, including several that are poorly removed by other methods. For example, formaldehyde gas can be decomposed through PCO technology, however, it is not effectively removed from air by cleaning methods based on adsorption (e.g., activated carbon containing media)[12]. Research has demonstrated the formation of partially oxidized byproducts, specifically volatile aldehydes such as formaldehyde and acetaldehyde from poorly designed PCO systems and warrants further investigation[17]. However, some PCO reaction chambers are so well designed that they have been utilized by NASA as a means to control ethylene gas in the agricultural processes in space. Unlike commercial buildings, common residential housing typically lacks any type of system to facilitate outdoor air ventilation. As a consequence, typical residences have a greater propensity to accumulate potential air pollutants within the indoor space.

The term fine particles, or particulate matter 2.5 ($PM_{2.5}$), refers to tiny particles or droplets in the air that are two and one half microns or less in width that can be a concern for people's health when levels in air are elevated. $PM_{2.5}$ can reduce visibility and cause the air to appear hazy when levels are elevated. Outdoor $PM_{2.5}$ levels are most likely to be elevated on days with little or no wind or air mixing.

Particles in the $PM_{2.5}$ size range are able to travel deeply into the respiratory tract, reaching the lungs. Exposure to fine particles can cause short-term health effects such as eye, nose, throat and lung irritation, coughing, sneezing, runny nose and shortness of breath. Exposure to fine particles can also affect lung function and worsen medical conditions such as asthma and heart disease. Scientific studies have linked increases in daily $PM_{2.5}$ exposure with increased respiratory and cardiovascular hospital admissions, emergency department visits and deaths. Studies also suggest that long term exposure to fine particulate matter may be associated with increased rates of chronic bronchitis, reduced lung function and increased mortality from lung cancer and heart disease. People with breathing and heart problems, children and the elderly may be particularly sensitive to $PM_{2.5}$. As a result of these health implications, some municipalities may alert the public by issuing a $PM_{2.5}$ Health Advisory when $PM_{2.5}$ concentrations in outdoor air are expected to be unhealthy for sensitive groups[19].

There are outdoor and indoor sources of fine particles. Outside, fine particles primarily come from car, truck, bus and off-road vehicle exhausts, and other operations that involve the burning of fuels such as wood, heating oil or coal and natural sources such as forest and grass fires. Fine particles also form from the reaction of gases or droplets in the atmosphere from sources such as power plants. These chemical reactions can occur miles from the original source of the emissions. Some of the fine particles measured in the air are carried by wind from out-of-state sources. Because fine particles can be carried long distances from their source, events such as wildfires or volcanic eruptions can raise fine particle concentrations hundreds of miles from the event.

$PM_{2.5}$ is also produced by common indoor activities. Some indoor sources of fine particles are tobacco smoke, cooking (e.g., frying, sautéing, and broiling), burning candles or oil lamps, and operating fireplaces and fuel-burning space heaters (e.g., kerosene heaters). The United States Environmental Protection Agency (EPA) established National Ambient Air Quality Standards for $PM_{2.5}$ in 1997 and revised them in 2006 and 2015 [20]. National Ambient Air Standards are established to be protective of public health. The short-term standard (24-hour or daily average) is 12.0 micrograms per cubic meter of air (µg/m^3). These standards were later adopted by the California Air Resources Board (ARB) and the World Health Organization (WHO).

Outdoor air levels of fine particles increase during periods of stagnant air (very little wind and air mixing), when the particles are not carried away by wind, or when winds bring polluted air into the state from sources outside the state. In general, as the levels of $PM_{2.5}$ in outdoor air increase, the air appears hazy and visibility is reduced. These conditions are similar in appearance to high humidity or fog. The Department of Environmental Conservation and various municipalities in the United States provide $PM_{2.5}$ monitoring data and $PM_{2.5}$ forecasts on its web site [21].

When outdoor levels of $PM_{2.5}$ are elevated, going indoors may reduce exposure, although some outdoor particles will come indoors. If there are significant indoor sources of $PM_{2.5}$, levels inside may not be lower than outside. Some ways to reduce exposure are to limit indoor and outdoor activities that produce fine particles (for example, burning candles indoors or open burning outdoors) and avoid strenuous activity in areas where fine particle levels are high.

This study explores the impact of the Airocide APS-200 PM 2.5 PCO Unit on the degradation of PM 2.5 in a common household room to establish the efficacy of the unit relative to its use as an indoor air cleaning device

Materials and Methods

The room selected for the test was a living room in a common home near Tampa, FL. The dimensions of the room were measured to be approximately 1,000 ft^3. This is a standard size for homes in the area where the test was performed. It is also the average size of a common hotel room. Since both locations were considered optimal locations for the APS-200 PM 2.5 PCO Unit; this testing location was determined to be optimal. Approximately 5 lbs (134.08 cm^3) of Tidy Cat litter was distributed on the carpet and then vacuumed. This was determined by previous testing to raise the $PM_{2.5}$ levels interpreted by the meter. The meter was a Dust Trak II, and it was positioned on a ledge overlooking the living room.

Base Line Testing.

After dispersal of the Tidy Cat litter and subsequent vacuuming. The Dust Trak II was primed, zero-calibrated, and test mode was initiated at 11:30 am on Friday November 18th, 2016. It took measurements in one second intervals for a total of one hour. Once all of the data was collected; the average of the 3,600 tests was calculated to be .061 mg/m^3. The Airocide APS-200 PM 2.5 PCO Unit was then turned on in “High Mode”

Twenty Four Hour Test

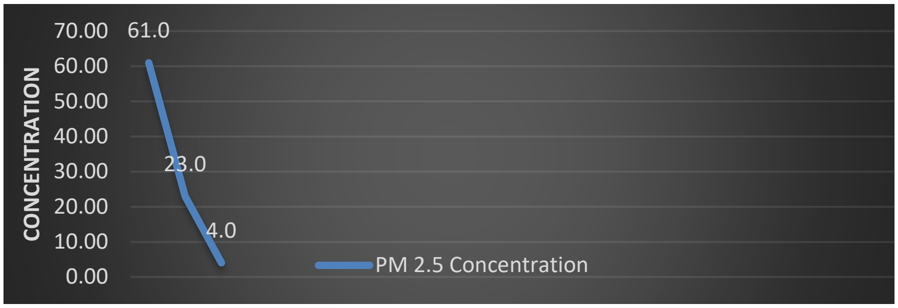
The Airocide APS-200 PM 2.5 PCO Unit was allowed to operate in “High Mode” for a period of exactly 24 hours. At 11:30 am on Saturday November 19th, 2016 the second test was performed. The Dust Trak II was primed, zero calibrated, and test mode was initiated. It took measurements in one second intervals for a total of one hour. Once all of the data was collected; the average of the 3,600 tests was calculated to be .023 mg/m^3. This was a 62.3% reduction in the $PM_{2.5}$ level over the 24 hour period.

Forty Eight Hour Test

The Airocide APS-200 PM 2.5 PCO Unit was allowed to operate in “High Mode” for an additional period of exactly 24 hours. By 11:30 am on Sunday November 20th, 2016 the APS-200 PM 2.5 PCO Unit had been in operation for a total of 48 hours. The Dust Trak II was primed, zero calibrated, and test mode was initiated. It took measurements in one second intervals for a total of one hour. Once all of the data was collected; the average of the 3,600 tests was calculated to be .004 mg/m^3. This was a 93.4% reduction in the $PM_{2.5}$ over the 48 hour period.

Results

Graph 1: Concentration of $PM_{2.5}$ in Micrograms Per Cubic Meter



Discussion

The efficacy of the recently designed Airocide APS-200 PM 2.5 PCO Unit is to be expected. Airocide used the original NASA PCO reactor design used aboard the International Space Station to remove VOCs. It was determined by NASA, and in later testing, to be efficacious in removing Ethylene[24] (a VOC which acts as hormone in the fruit maturation process[23]). The PCO process has also been determined to be efficacious in removal of microbiological specimens [22]. The original NASA PCO reactor was modified to mitigate the entire spectrum of $PM_{2.5}$ through the addition of a hospital grade MERV-12 rated media, a Carbon/Permanganate media, and through the application of the NASA PCO catalyst to woven glass. The efficacy of Airocide's NASA PCO reactor design has been well established in peer reviewed research[22]; The $PM_{2.5}$ Unit is the next successful application of Airocide's technology.

Conclusions

This study revealed that the Airocide APS-200 PM 2.5 PCO Unit had a positive effect on the reduction of $PM_{2.5}$. The operational principle behind the TiO_2 PCO reaction mechanism is generally non-specific with regards to the chemical bonds targeted in the PCO process, and this is further enhanced by recent reactor modifications detailed previously. Therefore, it is reasonable to extrapolate that the similar results would be expected if the Airocide Unit encountered other categories of PM, VOCs, microbiological specimens, and organic particulate matter. This is supported by existing published literature on PCO. In conclusion, this study revealed that the Airocide Unit had a positive effect on the reduction of $PM_{2.5}$ in the household environment and that the Airocide APS-200 PM 2.5 PCO Air Cleaning Unit would be effective in the control of general household or hotel room $PM_{2.5}$.

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