

Clean-up of Contaminated Indoor Air Using Photocatalytic Technology

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ABSTRACT

A number of Sick Building Syndrome studies have concluded that microorganisms, endotoxins and VOCs in indoor air are involved in the development and/or aggravation of allergies and illnesses in buildings. The photocatalytic indoor air disinfection and detoxification technology provides one of the most viable solutions to the growing need to remEDIATE and purify contaminated indoor air. The experiments were conducted in a stainless steel environmental chamber to quantitatively measure the photocatalytic VOC destruction using Acetone as a representative VOC. While monitoring the VOC destruction, carbon dioxide (CO₂) levels were also measured. By performing a mass balance between the VOC destruction and CO₂ production, the photocatalytic technology was found to be completely effective. Dark control experiments were performed for each condition to confirm the validity of each experiment. The photocatalytic technology tested in these experiments was demonstrated to completely oxidize acetone at normal indoor air atmospheric conditions.

INTRODUCTION

Photocatalytic technology can provide the most viable solution to the growing need for purifying indoor air contaminated with microorganisms (bacteria, viruses, mold, etc.) and volatile organic compounds (VOC's). Scientific investigations at the University of Florida performed by Goswami et al. (4) showed the effectiveness of this technology for air disinfection. Another study by the authors also showed the technology's effectiveness in destroying bioaerosols and dust mite allergen contaminants in indoor air (1, 5-7). The present study was conducted to demonstrate its effectiveness in destroying VOCs. This photocatalytic technology involves the action of low energy UV light (black light) on a catalyst in the presence of water vapor which generates hydroxyl radicals that oxidize and destroy microorganisms and VOCs in the air. As a result the microorganisms and VOCs present in the air are converted to CO₂ and H₂O and other minerals. The photons from black light are safe for human exposure and do not produce

ozone. Efficiency of destruction of VOCs and microorganisms varies with the fluctuations in humidity, residence time, and temperature (4-7, 9, 12-14, 17). The photocatalytic reactor, under controlled air velocity, residence time, and relative humidity, causes complete destruction and mineralization of microorganisms and volatile organic chemicals to form carbon dioxide and water.

The following laboratory experiments were performed in a stainless steel environmental chamber. Acetone was used as a representative VOC. Experiments performed on other VOCs indicate a strong correlation between acetone (a low molecular weight ketone) PCO (photocatalytic oxidation) and other compound classes. Alcohols (2, 11, 15, 17), aldehydes (12, 15, 17, 19), amines (8), aromatics (9-10, 12, 15, 16), ketones (15, 18), and halogenates (3) have all been examined in PCO experiments.

METHODS

Experimental Chamber

Experiments were conducted in an environment controlled room as shown in Figure 1 with dimensions of 6' X 6' x 3 1/2' (volume= 126 cuft). The experimental chamber was set up with a VOC generating unit, a sampling port, temperature and humidity probes. External power switches were used to control operation of all electrical devices inside the chamber remotely. A portable compressor driven nebulizer was used to adjust the internal relative humidity to 50% (common RH found in an air-conditioned space). Proper air mixing was achieved using a fan placed inside the chamber. This fan was only used during VOC generation and water nebulization.

VOC and CO₂ Sampling

An on-line gas chromatograph (GC) was used to determine the VOC and CO₂ concentration in the air circulating inside the chamber. Varian model 3700 GC with dual flame ionization detector (FID) was used for monitoring the VOC and CO₂. For acetone, a HP-624, 30-meter long and 0.53-mm diameter column was used. For CO₂, a 6-ft long 1/8" SS column packed with Carbosphere™ was used.

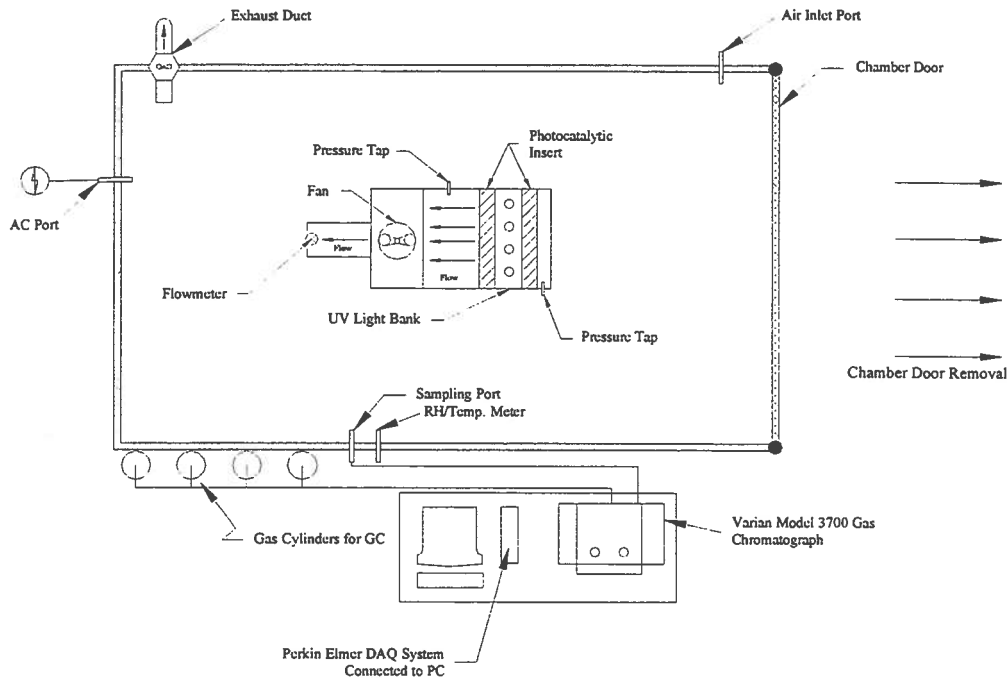


Figure 1: Schematic of Experimental Set

Because the FID is not sensitive to CO_2 , the detector was preceded by a heated catalyst (nickel based) which used hydrogen to reduce the CO_2 to methane which the FID can measure. Column temperature was 75°C . A PE Nelson 900 series interface and Turbochrom Navigator™ controlled the data collection and sampling sequence.

The sampling system consisted of a length of $1/16''$ OD stainless steel tubing with one end inserted through the sampling port, and deep enough so that the tube opening could be suspended in the center of the experimental chamber. The other end was connected to a six port gas-sampling valve on the GC. The valve was fitted with a one ml sampling loop. The sampling sequence began by using a vacuum pump to draw air from the chamber, through the tubing, and into the sample loop. After 15 seconds, the vacuum was closed off. An additional 15 second period was given to allow the loop pressure to reach the pressure inside the chamber. This pressure was accepted to be one atmosphere. The sample valve was then switched to load the loop contents onto the GC column for analysis. All of this process of acquiring the sample and analysis was automated. The time interval between successive samples was 11 minutes.

Calibration

Calibration of both chromatographs was performed by analyzing commercially prepared gas standards (Matheson Gas, Rutherford). A Tedlar™ bag was filled with the standard, and then attached to the GC sample inlet and the sampling sequence was performed as described previously. The GC's response to the standard was then used to quantify the closed chamber air samples

VOC Generation

Acetone generation in the chamber was accomplished by evaporating a known volume of pure acetone liquid in an Erlenmeyer flask on a hot plate. A circulating fan was used to facilitate proper mixing. Before every test, the chamber air was replaced with fresh air that was tested by the GC to confirm that no significant concentrations of VOCs were present.

Test Module

The air inside the chamber was circulated through the test module. The test module consisted of a catalytic or non-catalytic reactor (Flow cross-section of $16'' \times 5''$), bank of lights, a speed controllable blower, pressure taps and an inline velocity meter. The bank of lights consisted of four black light lamps with output in the range of 320-380 nm wavelength output. Pressure differential across the reactor area was measured with a differential

manometer. Airflow was calculated from air velocities measured using a hot-wire anemometer.

RESULTS

Prior to each experiment, airflow and relative humidity in the chamber were adjusted to the desired test condition. When the desired conditions were achieved, the test module and lights were turned off and acetone was introduced into the chamber. Further adjustments in relative humidity were made after acetone evaporation. Fluctuations in temperature were also partially dependent on the ambient air temperature. Attempts were made to reduce the impact this had on the test results, however, some temperature variations did occur, thereby also changing the internal relative humidity. A temperature and relative humidity range is given for each experimental run performed.

Four different photocatalytic reactor and light combinations were used to show the PCO effectiveness in destroying acetone. Two reactor sets were prepared. The photocatalytic reactor was an aluminum matrix support coated with a titanium dioxide based proprietary catalyst (UAT10). A control reactor was prepared with a similar aluminum matrix but with no catalytic coating. The total surface area for each reactor set was 43.8 sq ft. Each reactor was used for two experimental combinations. The first was a test with the reactor illuminated with the BLB (Black light blue) light source. This demonstrated photocatalysis and photolysis with the catalytic and uncoated reactors respectively. The second test was performed with the lights not illuminated. This demonstrated any adsorption and CO₂ production not associated with photocatalysis. The photocatalytic reactor was used for an additional photocatalytic test to show data reproducibility.

Non-Catalytic Reactor-Dark

Figure 2 shows the data from the test performed with the noncatalytic reactor set with the BLB lights not illuminated. The temperature range was 28.4-30.2°C and the range for the relative humidity (RH) was 48.4-60.3 %. The acetone level decreased by 2.58 ppm in 990 minutes with CO₂ decreasing by 13.20 ppm. These values correspond to 5.2 and 1.6 % changes in acetone and CO₂ respectively.

Non-Catalytic Reactor-Illuminated

Figure 3 shows the data from the test performed with the noncatalytic reactor set illuminated by the BLB lights. The temperature range was 28.4-30.2°C and the range for the relative

humidity (RH) was 44.7-50.8 %. The average light intensity for the BLB bulbs at 5-1/16" was 1.54 W/m². The acetone level decreased by 2.58 ppm in

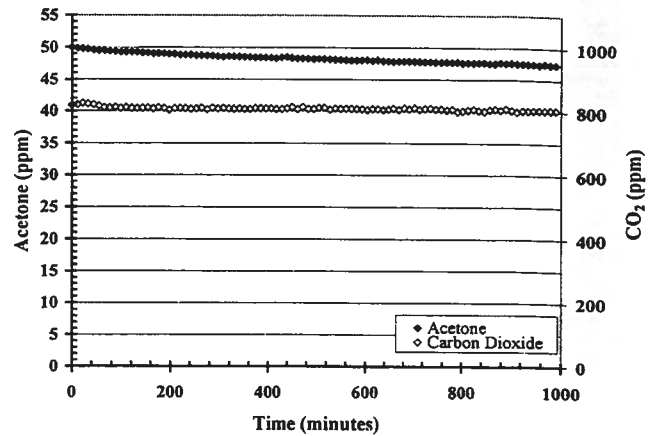


Figure 2: Non-Catalytic Reactor with No Illumination (control)

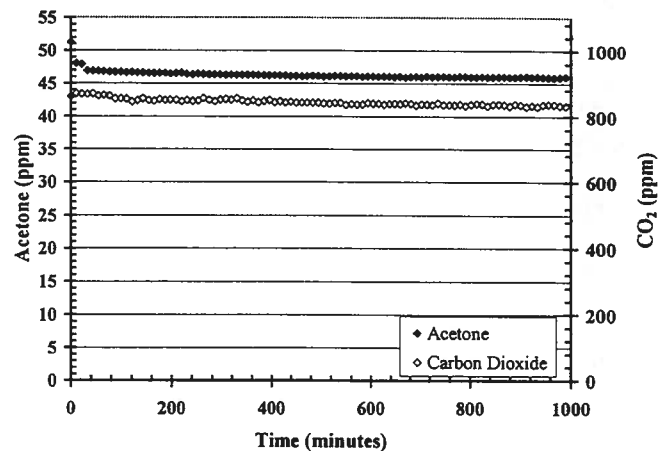


Figure 3: Non-Catalytic Reactor with Illumination (Photolysis)

990 minutes with CO₂ decreasing 13.2 ppm. These values correspond to 5.2 and 1.6 % changes in acetone and CO₂ respectively.

Photocatalytic Reactor-Dark (Adsorption)

Figure 4 shows the data from the test performed with the photocatalytic reactor set with the BLB lights not illuminated. The temperature range was 23.7-27.9°C and the range for the relative humidity (RH) was 52.9-61.0%. The acetone level decreased 3.31 ppm in 990 minutes with CO₂ decreasing 15.74 ppm. These values correspond to 7.1 and 2.0 % changes in acetone and CO₂ respectively.

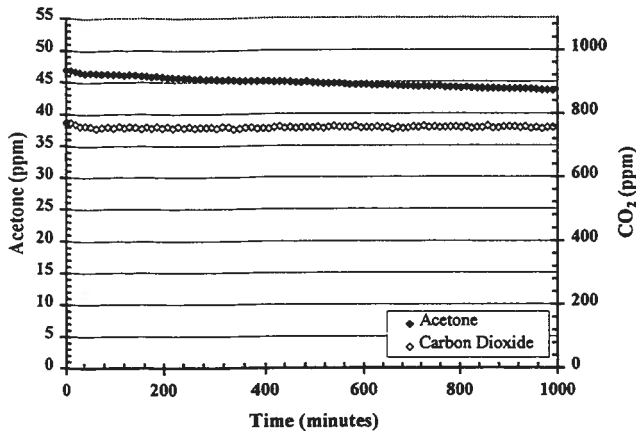


Figure 4: Photocatalytic Reactor with no Illumination (Adsorption)

Photocatalytic Reactor with Light (Photocatalysis)

Figure 5 shows the data from the two tests performed with the photocatalytic reactor set illuminated by the BLB lights. The data for the first experiment is as follows. The temperature range was 28.8-29.9°C and the range for the relative humidity (RH) was 49.1-50.23 %. The average light intensity for the BLB bulbs at 5 1/16" was 0.156 mW/cm². The acetone level decreased 48.18 ppm in 990 minutes with CO₂ increasing 155.62 ppm. These values correspond to 99.99% acetone destruction and 24.0 % CO₂ increase.

For the second set of experiments, the temperature range was 29.0-29.8°C and the range for the relative humidity (RH) was 49.5-60.4 %. The acetone level decreased 48.66 ppm in 990 minutes with CO₂ increasing 157.58 ppm. These values correspond to 99.53% acetone destruction and 25.6.0 % CO₂ increase.

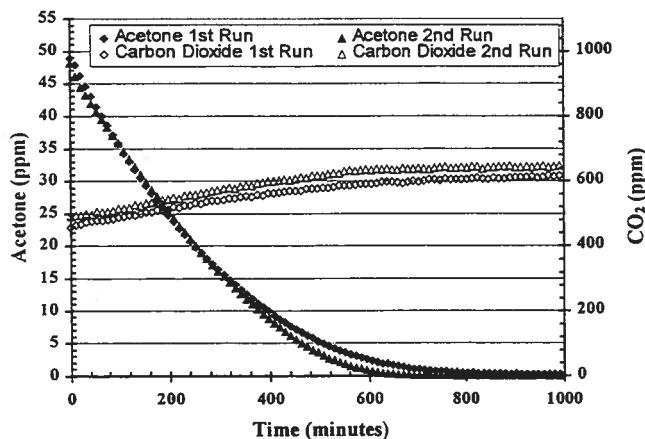


Figure 5: Photocatalytic Reactor with Illumination (Photocatalytic)

DISCUSSION

Previously reported research had demonstrated PCO effectiveness in destroying VOCs in various controlled environments. The test chamber used for these experiments examined a larger air volume (126 cuft) than typically examined in laboratory PCO studies. The test chamber was designed to simulate conditions in an indoor air environment. The relative humidities used for these experiments are also higher than humidities typically used in previous PCO studies on VOCs. Relative humidity levels typically found in air-conditioned environments fall around 50% RH. While research reported in the literature has examined moisture levels and how these levels change the PCO rates of different VOCs, few experiments have focused on conditions typically found in air-conditioned indoor air. The experiments performed here also utilized a higher VOC load than would be expected in most indoor air environments. Total volatile organic compound (TVOC) concentration is less than 1 ppm in normal indoor air, however a much higher concentration was employed in the present study to investigate the effectiveness of the oxidation process (conversion of VOCs, to CO₂).

Theoretically, for 48.18 and 48.66 ppm acetone to be completely oxidized, 144.54 and 145.98 ppm CO₂ would be produced. Corresponding to these values, 155.62 and 157.58 ppm CO₂ production was observed. The air used in the experimental chamber was not ultra-pure, filtered or sterilized in any way prior to the beginning of each experiment. Trace organic particulate (dust, microorganisms, pollen, and spores) simultaneously destroyed are probable sources for the additional CO₂ production. In addition to the CO₂ produced from acetone destruction in the first PCO experiment, an average additional 0.119 ppm was being produced from the destruction of the previously mentioned organic particulate. The second PCO experiment was producing an average of 0.086 ppm CO₂ per sample from organic particulate in addition to the CO₂ produced from acetone destruction.

CONCLUSION

Photocatalytic oxidation technology has been used for air purification in test environments. Based on the experimental results shown above, photocatalytic technology is effective in purifying indoor air. The technology has the ability to reduce the ventilation requirements below ASHRAE

standard 62-81 recommendations. This has tremendous implications in terms building operating costs.

Additional VOCs will be evaluated in the future to further bridge the gap between laboratory experiments and evaluations that have more meaning in indoor air-conditioned environments.

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