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# A Simple and Low-cost Photocatalytic Air Purification Test Method

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**Abstract.** The application of photocatalytic oxidation (PCO) in air purifiers (AP) to remove viruses, bacteria, and toxic gases in the air is intensively being studied, especially after the Covid-19 pandemic broke out. The testing method of PCO materials for AP purposes has been standardized through ISO 22197-4 (2013). However, the standard required a set of complex, high precision, and costly equipment. The present study demonstrates a simpler and low-cost test setup without compromising any accuracy in the overall result. The proposed test consists of a test chamber and mixing chamber, and sets of equipment installed in it. A 3D printer fabricated a PCO reactor, and TiO<sub>2</sub> was coated on the surface. Formaldehyde (HCHO) is used as a sample pollutant to be observed, injected into the test chamber. Before the measurement of the concentration of HCHO, the intensity of UV A LED was measured. Then, the amount of formaldehyde concentration was monitored online by indoor air quality measurement equipment. The result shows that the intensity of UV light was enough to generate a photocatalytic oxidation reaction. After 20 minutes of reaction, the HCHO concentration inside the chamber was decreased around 21.76%.

## 1. Introduction

Air purification (AP) becomes necessary equipment due to increasing people's awareness of indoor air health. Moreover, after the covid-19 pandemic started in late 2019, many studies have reported's effect to overcome indoor airborne transmission of such that virus indoors[1,2].

The AP has been designed to help eliminate dust particles, harmful gases such as volatile organic compounds (VOC), microorganisms (bacteria and virus), pollen grains, dust, mites, smoke particle, pet dander, and car exhaust fumes from the indoor air environment. Current technology inside the AP consists of various filters such as HEPA filter, electrostatic filter, and cloth activated carbon, and some added generated gas components such as plasma cluster, an ionizer (positive and negative ion or negative ion only), ozone generator (UV-C), or photocatalytic oxidation (PCO)[3,4].

Even though PCO technology was first introduced more than a century ago by Eibner[5], its development for AP application has been intensively researched in the last few decades[6]. The photocatalytic AP system has the main features: photocatalyst, UV source, reactor design and operation, and contaminants (pollutant or pathogen type). The most widely used photocatalyst is a binary metal oxide such as TiO<sub>2</sub>. To make a photocatalytic reaction of TiO<sub>2</sub> is simply enough to use sunlight as a



radiance source. However, during the operation is practical to use a UV-A source from an LED lamp. According to ISO 22197-4:2013 of the test method for AP of PCO materials[7], a comprehensive set of tests must be regulated for reactor design and operation, including test chamber, reactor chamber, gas flow meter, standardized gas sample, and gas analyzer. More or less similar to another PCO testing performance, they required a set of complex, high precision, and costly equipment[8–13].

The currently proposed design has a simple way of carrying out the PCO test with less equipment and less preparation for the gas sample to be tested. Formaldehyde (HCHO) is one of the common VOC contaminants and was used in this study. The objectives of this study are:

- Design and construction test chamber for photocatalytic AP test method.
- Measure the light intensity of UV-A LED used in the reactor chamber.
- Measure the degradation of concentration of HCHO sample gas in the test chamber.

## 2. Design Consideration

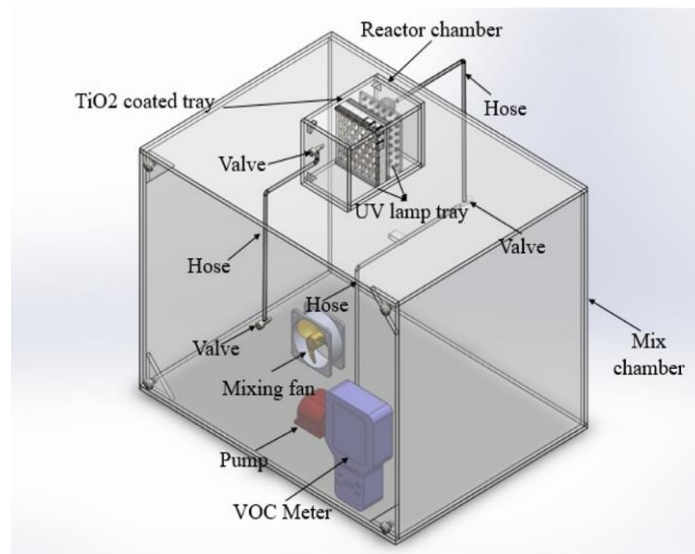
The design consideration refers to an existing test method, as shown in Table 1. In this study, an open-loop model of the test chamber was made. The UV light source came from UV-A LED. This study did not consider the effect of humidity during measurement, and no humidity control equipment was used. HCHO gas as pollutant gas was used and monitored directly by IAQ meter. PCO reactor is sprayed to make a thin layer of TiO<sub>2</sub>.

**Table 1.** Test chamber design consideration for various PCO testing

Ref	UV type	Test chamber	PCO reactor	Pollutant evaluation	Model	Humidity control	Extra equipment	Gas sample and pollutant
[7]	UV	photoreaction Reactor	-	Gas chromatography analysis	Open-loop		Valve and pressure gauge, Nebulizer	Formaldehyde, Compressed air
[8]	UV	Loop of Ducting	dip-coated in a TiO <sub>2</sub> (Degussa-P 25) slurry	-	Close loop	Nebulizer	Blower fan	Air, S. epidermidis, B. subtilis, A. niger, P. citrinum
[9]	UVA and UVB	Photocatalytic reactor inside Environmental chamber	Sprayed TiO <sub>2</sub> coating	Nox chemiluminescence analyzer	Close chamber	-	Homogenization fan	Reaction chamber
[10]	UV	Tunnel model	TiO <sub>2</sub> coated Ni Filter	Gas chromatography-mass spectrometry (GC-MS) High-performance liquid chromatography (HPLC) PID VOC detector	Open-loop	Humidifier	Pressure gauge, VOC injector, Rotameter	Compressed air, Toluene (aromatics), methyl ethyl ketone (ketones)

### 2.1. Proposed Design

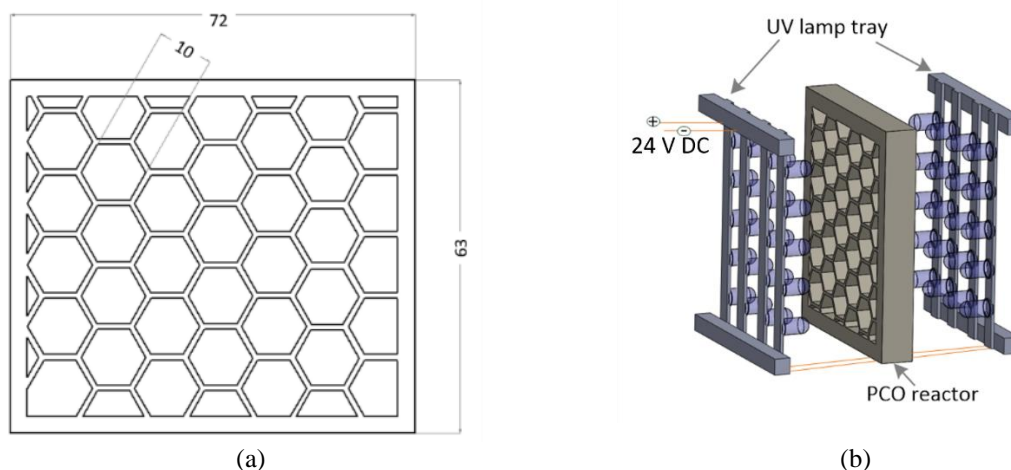
The proposed design in Fig 1. consists of two main parts; a mixing chamber and a reactor chamber. The mixing chamber is connected to the reactor chamber through a Teflon tube with a diameter of 6 mm. The mixing chamber is a transparent acrylic cube with 30 cm x 30 cm x 30 cm. The same acrylic material was used to construct the reactor chamber. Thus, the dimension of the reactor chamber is 82 mm x 73 mm x 120 mm.



**Figure 1.** Design of test chamber

The sample pollutant contained HCHO gas separated from the mixing chamber by a valve used to control the incoming pollutants. The mixing fan and hand-held IAQ meter are installed inside the test chamber and operated during the test. This IAQ meter enables the detection of related sample pollutants with less than 15% error detection. The range of HCHO that can be detected by IAQ meter varies from 0.001 – 1.999 ppm.

The reactor chamber consists of a PCO reactor and UV lamp trays. The PCO reactor mimics a honeycomb shape. The honeycomb shape (hexagonal) was chosen due to its high mechanical strength, high reaction rea, and intermediate convective mass transport rate [14]. This shape is shown in Fig. 2(a). The reactor is made of PLA+ plastic material made by a 3D printer. The reactor's dimension is 72 mm x 63 mm in length and width, respectively, with the 10 mm depth. Ecolala Permanent Guard (contains TiO<sub>2</sub>) coated the available surface area. The total effective area is 19,787 mm<sup>2</sup> and calculated by SolidWorks software.



**Figure 2.** (a) Honeycomb shape of PCO reactor monolith. All dimensions are in millimeters. (b) The arrangement of PCO-UV A LED.

UV-A LED with a typical wavelength of 390 – 400 nm is used. This UV-A LED with a power of 1.92 W is arranged in four rows and five columns on the two trays facing both sides of the PCO reactor, as shown in Fig. 2(b). Before the HCHO measurement, the intensity of the LED is measured by ML8511 UV sensor. This sensor can detect the UV wavelength from 280-400 nm within a range of output between 0 – 15 mW/cm<sup>2</sup>. No background light was detected before the measurement.

## 2.2. HCHO Measurement

The test procedure started with injecting air containing HCHO in a chamber. The sample pollutant was injected while the reactor valve was closed. First, let the pollutant mix with background air, indicating a constant IAQ meter concentration. The volume of air pollutants was 10 ml, 20 ml, and 30 ml. The next step is to turn on the fan simultaneously by opening the reactor valve to circulate the mixture gas to the reaction chamber. The gas passes through the PCO reactor, and it continues to recirculate for around 20 minutes.

The percentage of degradation  $D$  of HCHO was calculated as follows:

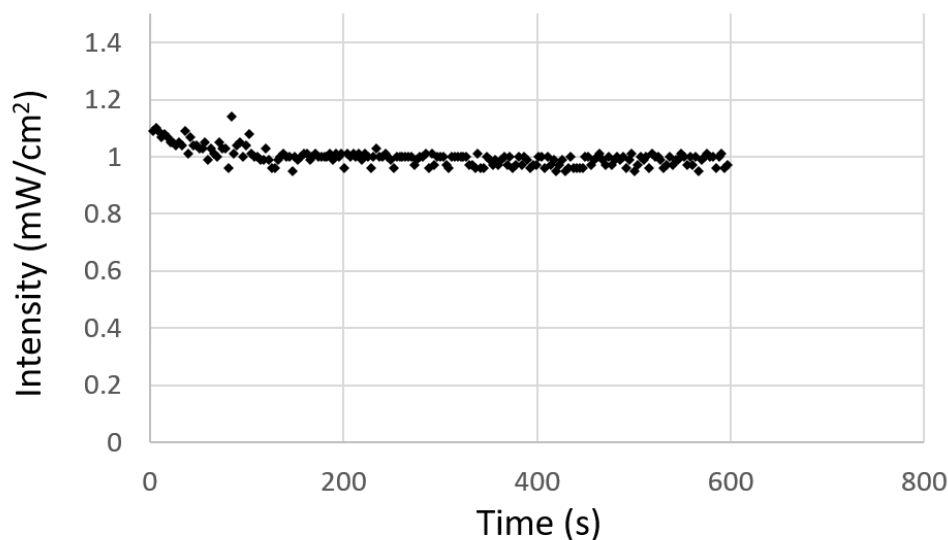
$$D = \left| \frac{C_f - C_i}{C_i} \right| \times 100\% \quad (1)$$

where  $C_i$  and  $C_f$  are measured HCHO concentrations at initial injection and final condition, respectively.

## 3. Result and Discussion

### 3.1. UV Light Intensity

The intensity of UV-light detected by the sensor ML8511 was shown in Fig. 3. The average value during 10 minutes measurement was 0.999 mW/cm<sup>2</sup> with a standard deviation of 0.031. This result was lower than the typical ambience UV light intensity around 4-6 mW/cm<sup>2</sup> reported during the peak hours [15,16]. Nevertheless, the result of light intensity measurement is feasible to generate a photocatalytic reaction since it was reported that an intensity of 0.6 mW/cm<sup>2</sup> could degrade 29.3% of VOC gas such as benzene from an initial concentration of 35 ppb in 3.8 min reaction time[17].



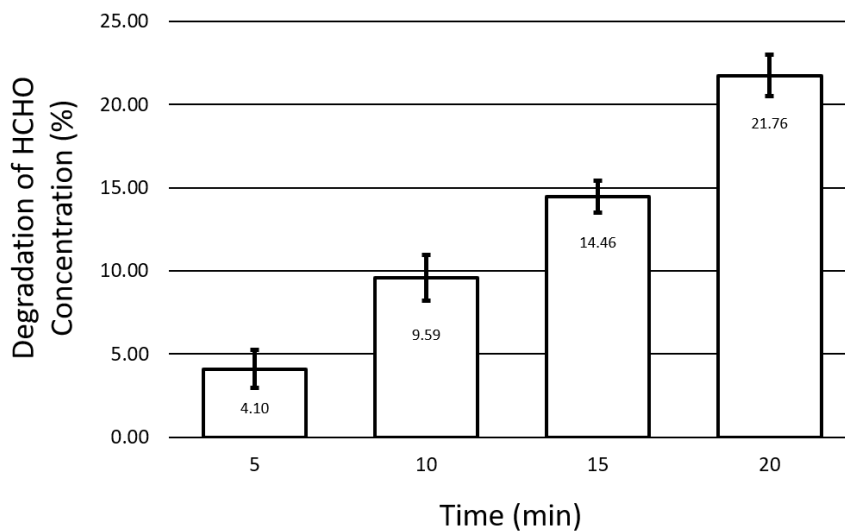
**Figure 3.** Result of UV-A LED intensity.

### 3.2. HCHO Concentration

**Table 2.** Result of HCHO concentration measurement

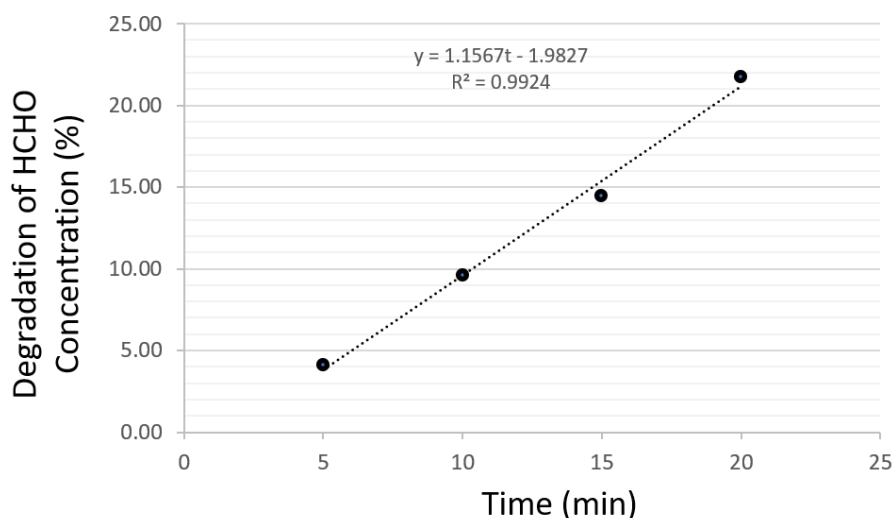
Amount of Air (ml)	Initial HCHO (ppm)	HCHO after 5 minutes (ppm)	HCHO after 10 minutes (ppm)	HCHO after 15 minutes (ppm)	HCHO after 20 minutes (ppm)
10	0.278	0.263	0.247	0.237	0.219
20	0.321	0.309	0.292	0.278	0.254
30	0.630	0.610	0.576	0.534	0.484

The concentration of HCHO was measured, and the results are shown in Table 2. All the experiment condition shows that the concentration of HCHO was degraded over time. The percentage of degradation of HCHO concentration can be seen in Fig. 4. The result is the average of three experimental conditions. After 5 minutes, the concentration of HCHO degraded to 4.10% with a standard deviation of 1.15%. Ten minutes later, the degradation of HCHO concentration was also detected and decreased to 9.10%, with a standard deviation of 1.38%. After 15 minutes, the concentration of HCHO degraded to 14.46% with a standard deviation of 0.95%. Finally, after 20 minutes, the concentration of HCHO degraded to 21.76%, with a standard deviation of 1.24%. The standard deviation of each measurement time was slightly small; therefore, the degradation of HCHO concentration seems to have a similar fashion. When the reactor chamber valve was open, the air containing HCHO pollutants passed the PCO reactor. Due to the photocatalytic reaction principle, the PCO reactor ( $\text{TiO}_2$  coated on the surface) interacts with light and absorbs UV light to oxidize solid hydroxyl radicals ( $\text{OH}^\cdot$ ). This  $\text{OH}^\cdot$  destroyed the chemical bond in HCHO to produce a more harmless substance in the form of  $\text{H}_2\text{O}$  and  $\text{CO}_2$ .



**Figure 4.** Average degradation of HCHO concentration over time.

The degradation of HCHO concentration during the test tends to have a linear relationship. The Fig.5. shows the linear relation of the percentage of decreasing the HCHO concentration. The value of the coefficient of determination  $R^2$  on the graph is nearly unity. The result of the linear regression model gives an insight that the data fit the linear model.



**Figure 5.** Linear relation of degradation HCHO over time.

#### 4. Conclusion

A test chamber for testing for the photocatalytic air purification test method was constructed. This device consists of mixing and a reactor chamber. A fan and pump circulate the air and IAQ meter to measure the HCHO concentration inside the mixing chamber. The reactor chamber consists of two UV-A LED trays and coated PCO reactor. The intensity of UV-A LED used in the reactor chamber is 0.999 mW/cm<sup>2</sup> and enough to generate the photocatalytic reaction. The concentration of HCHO degrades linearly over time. For example, after 20 minutes of reaction time, the concentration of HCHO is decreased around 21.76% from the initial condition.

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