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Design of UV-C LED Photocatalytic Reactor for Degradation of Volatile Organic Compounds

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Article

Ultraviolet light-emitting diodes are slowly replacing the applications of conventional UV lamps due to smaller foot-prints, non-toxic operation, and design flexibility of LEDs . Mercury-vapor UV lamp is a common source for high-energy ultraviolet photons (UV-C) in many applications. Photocatalytic degradation of VOC is one of the applications, where the conventional UV lamps are installed for the degradation of indoor pollutants. Typically, photocatalytic reactors are hollow-cylindrical tubes with the UV lamp placed at the center axis to fully illuminate the photocatalyst coated on the inner sidewall of the reactor . Unlike UV lamps, it is not straightforward to use the UV-C LEDs to design a photocatalytic reactor for the VOC degradation, because UV-C LEDs are usually pointsource with the limited light emission angle . Therefore, the emission angle of the UV-C LED is a key factor affecting the illumination of the photocatalyst in a LED-based cylindrical photocatalytic reactor. In this study, we have derived a condition to fully illuminate the photocatalyst coated on the inner sidewall of the cylindrical photocatalytic reactor equipped with the UV-C LEDs. The light intensity distribution on the surface of photocatalyst obtained from the optical ray-tracing simulations. Finally, we have designed a UV-C LED photocatalytic reactor from our derived condition and tested its VOC removal efficiency. DESIGN AND SIMULATION shows the schematic of the UV-C LED photocatalytic reactor in a cross-sectional view. The inner sidewall of the cylindrical photocatalyst reactor is coated with the TiO_2 nanoparticles by the Sol-gel method. The UV-C LEDs are mounted on the sides of a supporting column positioned at the center axis of the cylindrical reactor. Nface represents the number of faces in the LED supporting column. The DC Fan installed at the top of the reactor pulls the air through the photocatalytic reactor from the outside atmosphere. It depicts the 3-D simulation model of the photocatalytic reactor with the Nface=2 in the supporting column. Length and inner-diameter of the photocatalytic reactor are denoted as L and D, respectively. D=2*R, where R is the inner-radius of the reactor. In our design, the center-to-center distance between the UV-C LEDs on each face of the supporting column is the same as the inner radius of the reactor. (a) Cross-sectional view of the UV-C LED photocatalytic reactor and (b) 3-D ray-tracing simulation model. UV-C light intensity distribution on the photocatalyst surface is obtained from the ray-tracing simulation done using TracePro. In the simulation, the emission angle (θLED) and the wavelength (λ) of source LED are set as 120˚ and 280-nm, respectively. It shows the UV-C intensity distribution obtained from the ray-tracing simulation of the model , the UVC light is not fully shined on the cylindrical photocatalyst surface, we observe a very low and almost no intensity distribution on the target surface. This is because the Nface=2 of the LED supporting column is not appropriate for the UV-C LEDs with an emission angle of 120˚ in the cylindrical photocatalyst reactor. Consequently, we derived a condition to fully illuminate the cylindrical photocatalyst surface which mainly relates the Nface of the LED supporting column and θLED of the light sources used. (a) Intensity distribution on the inner sidewall of the simulation model and (b) schematic illustration of the UV-C LED emission in an ideal case with Nface=2 and Nface=3 in the top-view. Figure 2(b) illustrates the schematic (top-view) of the cylindrical photocatalytic reactors with the Nface=2 and Nface=3. The area of photocatalyst (Ac) coated on the inner sidewall of the cylindrical reactor is Ac=πD*(L+R). The illuminated photocatalyst area (AILL) in the ideal case is derived in equation which explicitly shows the relationship between the Nface and θLED. $AILL = Nface \times \theta LED \ 2\pi \times Ac$ We can estimate the ratio of illuminated photocatalyst area in the ideal case using equation (1). As depicted , ideally, if Nface=2 and Nface=3, AILL=2/3 Ac and AILL=Ac, respectively. In an ideal situation, the LED supporting column with the Nface=3 is sufficient to completely illuminate the photocatalyst on the inner sidewall of the cylindrical reactor, when the θLED =120˚. However, in reality, the angular intensity distribution of UV-C LEDs are not uniform. We have compared the simulated intensity distribution on the photocatalyst surface for the Nface=3 and the Nface=4 in , when the Nface=3, the cylindrical photocatalyst surface is fully illuminated but the intensity distribution is partially uniform. The uniformity of the intensity distribution is improved for the Nface=4. Therefore, we derive the condition to fully illuminate the photocatalyst coated on the cylindrical surface from the simulated light patterns that the Nface*θLED ≥ 360˚. . Ray-tracing simulation models (up) and the simulated light patterns (down) for the Nface=3 and 4 of the LED supporting column. EXPERIMENT AND RESULT The fabricated UV-C LED photocatalytic reactor based on the derived condition Nface*θLED ≥ 360˚ , where the LED supporting column with the Nface=3 is installed to fully illuminate the photocatalyst coated on the cylindrical inner sidewall (not shown). The output power of each UV-C LED is 10 mW at the peak wavelength of 280 nm. Since three UV-C LEDs are mounted on each side of the LED supporting column, the total output power is 90 mW. The air delivery rate of the DC Fan is 18.5 CFM. The electrical power consumption of the designed reactor is about 5 W. Photos of the UV-C LED photocatalytic reactor (left) and the LED supporting column (right), and (b) the experiment setup. The VOC degradation efficiency of the designed photocatalytic reactor is validated by the experiment. An acrylic hermetic chamber is used to test the photocatalytic reactor and the dimensions of the chamber are 30 cm (length) X 30 cm (breadth) X 30 cm (height). It shows the experiment setup. depicts the measured degradation performance of the designed photocatalytic reactor. The degradation efficiency of the Formaldehyde (HCHO) gas using the designed photocatalytic reactor is evaluated. The VOC gas concentration within the chamber is measured using gas chromatography. The initial HCHO gas concentration is approximately 8 ppm and after the 90 minutes of continuous reactor operation. The HCHO degradation efficiency of the designed UV-C LED photocatalytic reactor is about 79.66%. The HCHO concentration is almost reached zero but due to the limitation of the measuring instrument, we could not measure the concentration below 1 ppm. The measured degradation rate constant of the designed photocatalytic reactor is 0.1164 ppm/minute. Experimental degradation of the VOC (Formaldehyde) by the designed UV-C LED photocatalytic reactor. CONCLUSION In this study, we have designed and tested the cylindrical photocatalytic reactor with the UV-C LEDs installed on the faces of the center-axis supporting column. Nface*θLED ≥ 360˚ must satisfy to fully illuminate the cylindrical photocatalyst surface. The photocatalytic reactor is fabricated based on the derived condition and tested for VOC degradation. The degradation efficiency of the VOC is 79.66% and the measured degradation rate constant is about 0.1164 ppm/minute in our photocatalytic reactor.

Biography

Karthickraj Muthuramalingam worked in Indian institute of Technology and also worked for 5 years in U.V Leads Technology.

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Speaker Publications

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