Applying the activated carbon fiber filter supported with copper oxide catalyst to remove indoor VOCs

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ABSTRACT

HVAC (Heating, ventilating air conditioning) system is used to keep indoor air quality. The purpose of the traditional HAVC system is providing a comfortable environment and ventilating the indoor air pollutants. Recently, with the quality of life increasing, people have more requests for indoor air quality. However, we found that the HVAC system still stress indoor ventilation, and temperature and humidity adjusting. Therefore, this work tries to apply the feasible air-cleaning technologies to remove the indoor VOCs.

This work tries to apply the activated carbon fiber filter supported with copper oxide catalyst (CuO/ACF catalyst filter) for removal of indoor VOCs. Formaldehyde was chosen as the target pollutants. The experiments were conducted in a stainless steel chamber equipped with a simplified HVAC system. A CuO/ACF catalyst filter was used in this simplified HVAC system. The total air change rates were controlled at 0.5 and 1.0 hr^{-1}, fresh air change rates were controlled at 0.18 and 0.36 hr^{-1}, and relative humilities (RHs) were controlled at 30% and 70%. When using the CuO/ACF catalyst filter in HVAC system, the first-order decay constant of formaldehyde found in this study ranged from 0.425 to 0.491 (hr^{-1}) under different concentration of formaldehyde, from 0.425 to 0.618 (hr^{-1}) under different total air change rates, from 0.425 to 0.689 (hr^{-1}) under different fresh air change rates, and from 0.425 to 0.451 (hr^{-1}) under different RH.

1. INTRODUCTION

More extensive use of insulation, tighter building design to reduce infiltration and increased ratios of recirculed/makeup air help to conserve energy but however cause rising in pollutant concentrations in interior spaces. This phenomenon causes the indoor air quality getting worse. On average, people spend as much as 87.2% of their time in indoor environment (Lance, 1996). The occupant's health is affected by the worse IAQ. Indoor volatile organic compounds (VOCs) play an important role in indoor air quality because it causes many diseases. Therefore, more and more air-cleaning technologies have been used to remove the indoor VOCs.

The building heating, ventilating air conditioning (HVAC) system is applied to keep IAQ. Air handling units in typical HVAC systems generally contain: (1) outside air intakes, plenums, ducts, and outdoor air; (2) filters and prefilters; (3) heating and cooling coils; (4) chiller and boiler; (5) cooling towers; (6) humidifier or dehumidifier; (7) supply fans; (8) supply ducts; (9) distribution ducts, boxes, and plenums; (10) damper; (11) return air plenums or ducts; (12) return fan; and (13) exhaust outlets (Yu et al., 2006). The primary function of typical HVAC systems is to control the temperature (thermal comfort) and relative humidity (RH) of the supply air. The components in a HVAC system are capable of removing the air pollutants contain the filter and prefilter. The mechanical (or electrostatic) filter is used for the control of the particulates. Few HVAC systems may be equipped with sorbent filters, such as active carbon filter, to remove gaseous pollutants, vapor or VOCs. However, the problem with using sorbent filters is the breakthrough of sorbent. When temperature or humidity increases, the adsorbed VOCs may be desorbed and then may re-enter the air stream. After exhausted, the sorbent filters need further treatment, such as regeneration or disposal of the spent sorbent.

This work tries to apply the CuO/ACF catalyst filter for removal of indoor VOCs. The technology of porosity adsorbent materials supported metal oxide was always used to removal organic pollutants in wastewater or waste gas (Okada, 1977; Chintawar & Greene, 1997; Zhu et al., 2000; Baek et al., 2004), but this technology is very few applied in indoor environment to reduce VOCs. However, copper oxide catalyst is a strong oxidizer, and the activated carbon fiber filter is most popular used to absorb indoor VOCs. When the activated carbon fiber filter supported with copper oxide catalyst, this technology would both have a stronger oxidizing and absorbing ability. Therefore, purpose of this work is using the CuO/ACF catalyst filter for removal of indoor formaldehyde in the HVAC system. The effects of total ACH, fresh ACH, relative humidity, and the formaldehyde concentration, on the removal characteristics of the formaldehyde were also conducted.

2. EXPERIMENTAL METHODS

2.1 Experimental setup

Figure 1 shows the setup of a small-scale HVAC system, which simplified and contained a tested chamber, a duct system (cross-section: 6 × 6 cm^2), a supply fan, a return fan, a pump, and an CuO/ACF catalyst filter (3.8 × 3.8 cm^2). The tested chamber was built by using stainless steel and the whole size is 80 × 80 × 80 cm^3. The CuO/ACF catalyst filter was applied to remove VOCs in the small-scale HVAC system. Two fans and a pump were used to keep a stable airflow and the set ACH (air changes per hour). In this HVAC system, the total airflow rate (Q_t) is contributed from the airflow rate for recirculation (Q_1) and the makeup air (Q_2). In this study, the clean air was used as the makeup air for easier operating and estimating the particle decay behavior in the system. At a fixed total airflow rate, we could change the clean air rate for further understand the effect of the clean air rate on the VOCs decay behavior. This study used the ACH to illustrate the effect of the airflow rate on decay of VOCs in the chamber. The total ACH means the total airflow per in the system the volume of the tested chamber (Q_t/V) and the fresh ACH is equal to the clean airflow per the volume of the tested chamber (Q_2/V). American Society of Heating, Refrigerating and Air-Conditioning Engineer (AHSRAE Standard 62-2001) (2001) suggested the lowest ACH of the indoor housing is 0.35 (1/hr) (ASHRAE, 2001). Elkilani and Bouhamra (2001) concluded that air exchange rates are 0.25-0.7 h^{-1} through HVAC system and greater than 1.0 h^{-1} and up to1.7 h^{-1} in case of openings. Thus we selected two total ACH (0.5, and 1.0 hr^{-1}) for the further comparing in this experiment. Also, two fresh ACH (0.18 and 0.36 hr^{-1}) were chosen in the study.

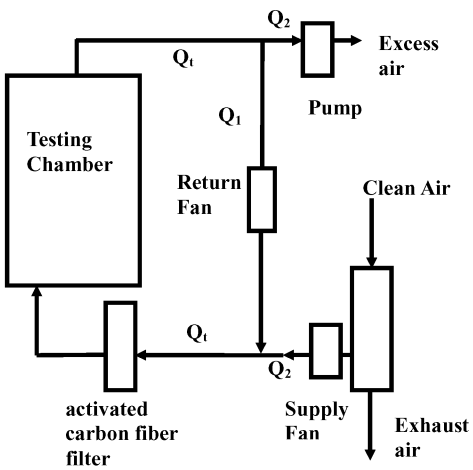

Figure 1. Schematic diagram of a small-scale HVAC system

This study considered the effect of relative humidity (RH) on particle decay behavior in HVAC system. Two RHs were used in this work. The RH of the particle-flow stream was modified by changing the ratio of the flow rate of the dry gas stream to that of the humidified gas stream generated by the water vapor saturator. The final RH of the particle-flow stream was measured using the Q-trak (model 8550, TSI Inc.). Two relative humidity conditions for experiments were 30% and 70% that stood for dry and humid condition respectively in this study.

Before the experiments started, the stainless steel chamber was conditioned for 6 hr to attain the required experimental conditions.

2.2 ACF filter

The catalyst filters used in this work were using the activated carbon fiber filter supported with copper oxide catalyst (CuO/ACF catalyst filter). The making process of CuO/ACF catalyst filter was shown below. The activated carbon fiber filters were putted in the copper nitrate solution. The concentration of the copper nitrate solution was 1 M (mol/L). After the filters were soaked, the filters were dried in an oven at 105˚C for 24 hours. And then the activated carbon fiber filters coated with copper nitrate were putted in the catalyst calcining system. After calcining in 500^{o}C, the activated carbon fiber filters coated with copper nitrate would become the CuO/ACF catalyst filter.

2.3 Mixing level of the test chamber

For understanding the mixing level of the test chamber (>80%), a fan was installed in the test chamber. The mixing level of the test chamber was calculated as below:

$$\eta_{mix} = \left\{ 1 - \frac{\sum_{i=1}^{n} \left[\left| C_{tr}(t_i) - C_{th}(t_i) \right| \times (t_i - t_{i-1}) \right]}{\sum_{i=1}^{n} \left[C(t_i) \times (t_i - t_{i-1}) \right]} \right\} \times 100\% \quad (1)$$

where η_{mix} (%) is the mixing level, t_i (hr) is the time when the i^{th} sample was taken, n is the serial number of the sample, and C_{tr} (t_i; ppm) is the gaseous tracer (CO_2) concentration at time t_i. C^{th} (t_i; ppm) is the theoretical tracer concentration under a completely mixing condition, and C^{th} (ti) can be calculated by the following equation:

$$C_{th}(t_i) = C_{tr}(0) e^{-Ach \times t} \quad (2)$$

in which C_{tr} (0) is the initial gaseous tracer concentration (ppm), and Ach is the air change rate of the test chamber (hr^{-1}). Q-Trak (TSI. 8550) was used to monitor the CO_2 concentration continuously. The mixing levels of test 1 and test 2 were 95.4% and 93.6%, respectively.

2.4 Sampling and analysis of VOCs

This work selected the formaldehyde as the target VOCs. The sampling apparatus for formaldehyde contained LpDNPH S10 air monitoring cartridges (SUPELCO) and a personal sampling pump (SKC). The sampling flow rate was 200 ml/min, and the sampling volume was 2000 ml. After sampling, the LpDNPH S10 cartridge was eluted with 2-ml aliquots of acetonitrile, and the eluate was collected to the 10-mL mark on a volumetric flask. The extract was analyzed with GC-photoionization detection ([GC-PID] HP5890 series II), and the injected volume was 2 L. The quantification was conducted by analyzing a series of reference solutions of formaldehyde with the GC system (HP5890 series II GC-PID). A calibration curve was created based on the analytic result of the reference solutions of formaldehyde.

3. RESULTS AND DISSCUSSIONS

3.1 Natural decay of the formaldehyde in HVAC system

Figure 2 plots the decay curve of 0.5-ppm formaldehyde in the small-scale HVAC system without using the CuO/ACF catalyst filter at total ACH of 0.5 (1/hr) and fresh ACH of 0.18(1/hr). The nature decay constant (kn) of 0.5-ppm formaldehyde is about 0.234 (hr^{-1}). The nature decay constants (kn) of 1.0-ppm formaldehyde are about 0.245 (hr^{-1}). The result also shows that when increasing the total ACH, the nature decay constant of 0.5-ppm formaldehyde would become 0.372 (hr^{-1}).

3.2 Decay constant of the formaldehyde with using CuO/ACF catalyst filter in HVAC system

Figure 3 implies the decay curve of 0.5-ppm formaldehyde in the HVAC system with using the CuO/ACF catalyst filter at total ACH of 0.5 (1/hr), fresh ACH of 0.18(1/hr) and RH of 30%. Decay constant (ka) of 0.5-ppm formaldehyde is about 0.425 (hr-1). It is finding that when using the CuO/ACF catalyst filter, the decay constant of the formaldehyde is obviously increasing. It is because that CuO/ACF catalyst is a strong oxidizer. Thus, the CuO/ACF catalyst filter would oxidize and remove formaldehyde effectively.

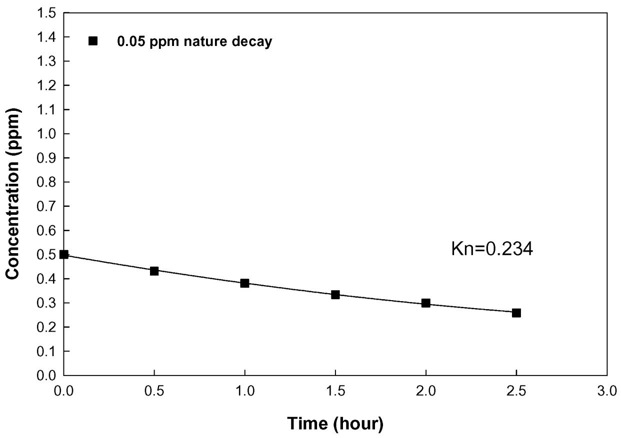

Figure 2. The natural decay of the 0.05-ppm formaldehyde

3.3 Effect of formaldehyde concentration

Figure 4 plots the decay curve of 1.0-ppm formaldehyde in the HVAC system with using the CuO/ACF catalyst filter at total ACH of 0.5 (1/hr) and fresh ACH of 0.18(1/hr). The decay constant (ka) of 1.0-ppm formaldehyde is about 0.452 (hr^{-1}). Figure 5 shows that when using the CuO/ACF catalyst filter in the HVAC system (total ACH of 0.5 (1/hr) and fresh ACH of 0.18(1/hr)), the decay constant (ka) of 2.0-ppm formaldehyde is about 0.491 (hr^{-1}). These experiment data present that the decay constant of the formaldehyde increases with the concentration of formaldehyde. It is due to that when concentration of formaldehyde is higher, more formaldehyde molecules would contact the CuO/ACF catalyst filter. Therefore, the higher-concentration formaldehyde would be reduced easier in the HVAC system.

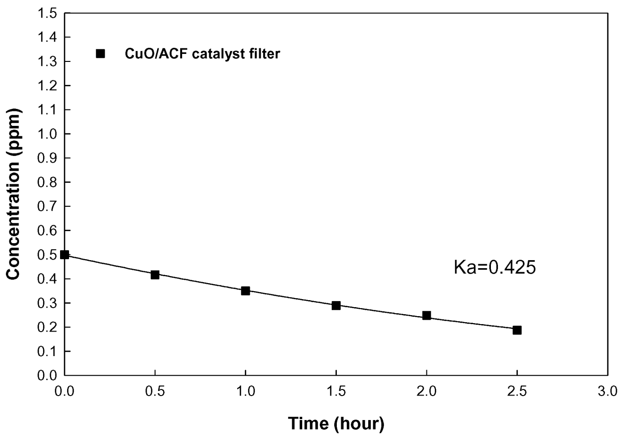

Figure 3. The decay behavior of the 0.5-ppm formaldehyde with using CuO/ACF catalyst filter (total ACH = 0.5 hr^{-1}, fresh ACH=0.18 hr^{-1})

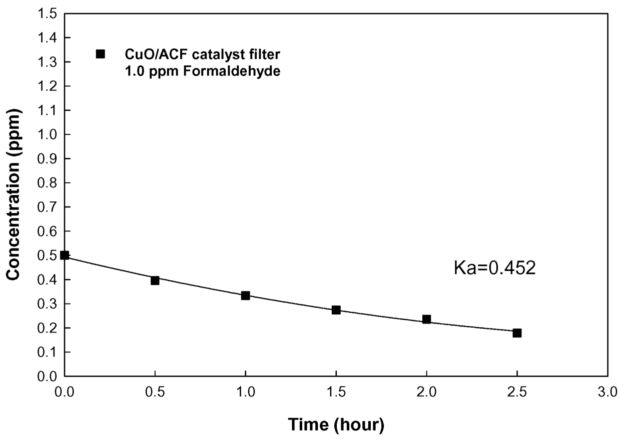

Figure 4. The decay behavior of the 1.0-ppm formaldehyde with using CuO/ACF catalyst filter (total ACH = 0.5 hr^{-1}, fresh ACH=0.18 hr^{-1})

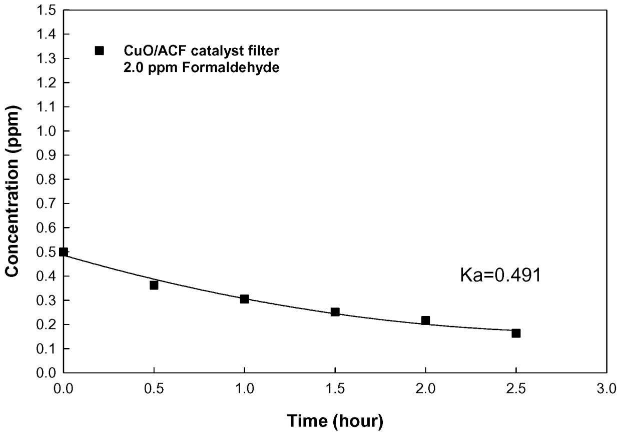

Figure 5. The decay behavior of the 2.0-ppm formaldehyde with using CuO/ACF catalyst filter (total ACH = 0.5 hr^{-1}, fresh ACH=0.18 hr^{-1})

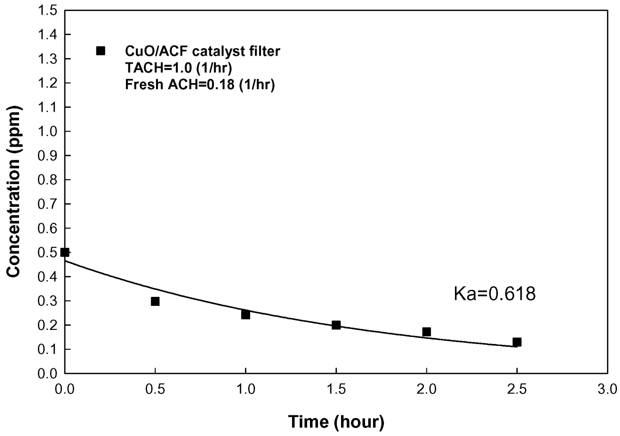

Figure 6. The decay behavior of the 0.5-ppm formaldehyde with using CuO/ACF catalyst filter (total ACH = 1.0 hr^{-1}, fresh ACH=0.18 hr^{-1})

3.4 Effect of ACH

Figure 6 implies the decay curve of 0.5-ppm formaldehyde in the HVAC system with using the CuO/ACF catalyst filter at total ACH of 1.0 (1/hr) and fresh ACH of 0.18(1/hr). The decay constant (ka) of 0.5-ppm formaldehyde is about 0.618(hr^{-1}). According to these results, when total ACH increases from 0.5 to 1.0 (1/hr), the decay constant of 0.5-ppm formaldehyde (with using the CuO/ACF catalyst filter) raises from 0.425 to 0.618. When increasing the total ACH and not changing the fresh ACH, the circulating rate in the HVAC system is increasing. It is the main reason that the decay constant raises with the total ACH.

Figure 7 shows the decay curve of 0.5-ppm formaldehyde in the HVAC system with using the CuO/ACF catalyst filter at total ACH of 0.5 (1/hr) and fresh ACH of 0.36(1/hr). The decay constant (ka) of 0.5-ppm formaldehyde is about 0.689 (hr^{-1}). According to these results, when fresh ACH increases from 0.18 to 0.36 (1/hr), the decay constant of 0.5-ppm formaldehyde (with using the CuO/ACF catalyst filter) raises from 0.425 to 0.689. It is due to that when increasing the fresh ACH, the more VOCs would be changed by clean air. Thus, the decay constant of formaldehyde raises.

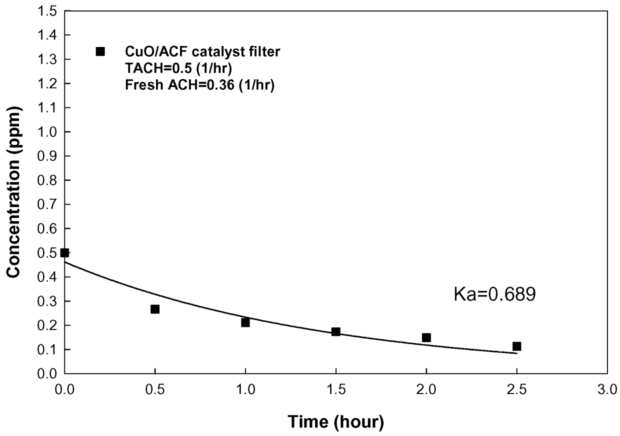

Figure 7. The decay behavior of the 0.5-ppm formaldehyde with using CuO/ACF catalyst filter (total ACH = 0.5hr^{-1}, fresh ACH=0.36 hr^{-1})

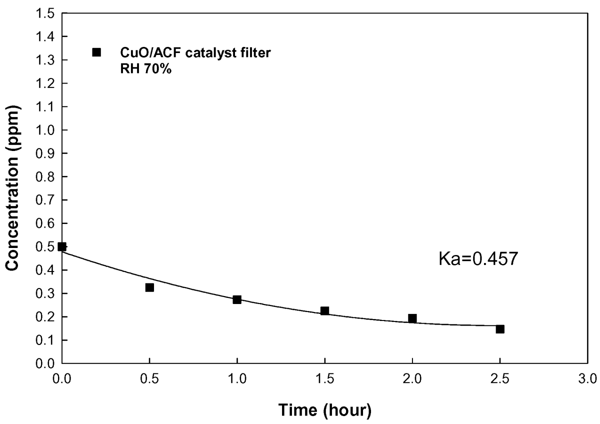

Figure 8. The decay behavior of the 0.5-ppm formaldehyde with using CuO/ACF catalyst filter at RH of 70% (total ACH = 1.0 hr^{-1}, fresh ACH=0.18 hr^{-1})

3.5 Effect of RH

Figure 8 implies the decay curve of 0.5-ppm formaldehyde in the HVAC system with using the CuO/ACF catalyst filter at RH of 70%, total ACH of 0.5 (1/hr) and fresh ACH of 0.18(1/hr). Decay constant (ka) of 0.5-ppm formaldehyde is about 0.457(hr^{-1}). According to experimental results, when RH increases from 30% to 70%, the decay constant of 0.5-ppm formaldehyde (with using the CuO/ACF catalyst filter) raises from 0.425 to 0.457. These results above demonstrate that the increase of RH has a positive effect on the effectiveness of the CuO/ACF catalyst filter for formaldehyde removal.

4. CONCLUSIONS

According to the results, CuO/ACF catalyst filter are capable of removing formaldehyde in HVAC systems. The kn of formaldehyde is dependent on the total ACH, whereas the ka is affected by total ACH, fresh ACH, RH, and concentration of formaldehyde. The decay constants of formaldehyde with using CuO/ACF catalyst filter increases with total ACH, fresh ACH, RH, and concentration of formaldehyde. The CuO/ACF catalyst filter could remove formaldehyde effectively, and the relevant mechanism needs further research.

5. ACKNOWLEDGE

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