A case study on the application of nano-confined catalytic oxidation (NCCO) air purification technology in ammonia gas removal in an office building

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ABSTRACT
A pilot test on ammonia (NH_3) control based on nano-confined catalytic oxidation (NCCO) air purification technology was carried out in an office building in Beijing. The source of ammonia probably came from the use of urea-containing concrete additive when the building was constructed several years ago. This phenomenon is commonly found in the buildings, which were constructed in winter, in the cities such as Beijing and Shanghai in North China. Many air treatment methods such as activated carbon, citric acid (neutralization), thermal baking, paint sealant, to name but a few, have been adopted by the property management to tackle the problem but in vain. The fresh air supply rate of the building was insufficient but it could not be increased due to the enormous retrofitted cost and the large influence to the existing tenants. Owing to the limited time, a number of portable air treatment devices equipped with NCCO feature was delivered to Beijing from Hong Kong. In order to acquire the outcome of the test for subsequent fine-tuning on the device performance in a short period of time, a real-time displaying total volatile organic compound (TVOC) monitor and dragger tubes were used during the test. Ammonia tests using NIOSH Standard Method 6015 were conducted simultaneously for verifying the real-time readings. This paper summarizes the performance of the NCCO based air treatment device on the treatment of NH_3. Two scenarios upon the NCCO device setting (i.e. ON/OFF) during night-time were predicted. Based on the findings, three feasible engineering solutions, with the considerations of the pros and cons of the system design, were evaluated.

INDEX TERMS
Air cleaning; Ammonia; Mitigation; SBS; Ventilation

INTRODUCTION
Urea-based additive can substantially reduce the temperature of concrete both at casting stage and during hydration process. For this reason, urea-containing concrete additive was added during the construction process of some buildings. This phenomenon is commonly found in the buildings, which were under construction in winter, in cities such as Beijing and Shanghai in North China. During the initial stage when the buildings have been occupied, a pungent smell caused by the emission of ammonia from building materials, is always detected. This nuisance problem becomes especially serious during summer time. Most importantly, ammonia is an irritant to the eyes and the respiratory tract. It also causes damage to the bronchial epithelium and the alveolar membrane at high concentration and long-term exposure (Omland, 2002). To reduce the ammonia concentration in these buildings became the objective of this study.

To treat this type of pollutant, various methods have been introduced. Adsorption of pollutants into the activated carbon filter is one of the common methods for odour control. However, the heterogeneously porous structure of activated carbon leads to competitive

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adsorption between water vapour and the pollutant, and eventually reduces its effectiveness in removing the pollutant (Alcaniz-Monge *et al.*, 2002). Moreover, heat generated from the adsorption process causes polymerization of the structure of activated carbon, and this degradation of structure further decreases the material's ability to adsorb the pollutant.

Synthetic zeolite, unlike activated carbon, exhibits selectively adsorption of volatile organic compounds (VOCs) depending on its structural characteristics. Zeolites are hydrated, crystalline tecto-aluminosilicates, $x\mathrm{M}[\mathrm{Al}_x,\mathrm{Si}_{1-x}]\mathrm{O}_2]_n\mathrm{H}_2\mathrm{O}$ where $x < 0.5$. They are constructed from aluminosilicates, which have negatively charged oxide frameworks. They are charge balanced by alkali (e.g. K^+, Na^+) or alkaline earth (Ca^{2+}, Ba^{2+}) cations. Natural zeolites usually have heterogeneous structures, and have less selectivity on adsorption. Synthetic zeolites are more effective as an adsorbent of a particular pollutant. Preliminary work has been conducted by the same research group recently to compare the performance of removal of VOCs and formaldehyde using both the synthetic zeolite, NaP1 and activated carbon (Law *et al.*, 2001). It was noted that the VOCs removal efficiency of using synthetic zeolite was better than using activated carbon by 15–20% under laboratory testing environment and a much faster removal rate was also observed under a similar pressure drop.

When zeolite is used alone, the pollutant is adsorbed and trapped within the pores of the zeolite, where it is secured until it is released upon zeolite regeneration. A common method of regeneration is thermal treatment (Brilhac *et al.*, 2002). In the case of a sole zeolite filter, the pollutants are not decomposed, but are merely released from the pores during the regeneration process. However, if the pollutants are oxidized or decomposed into some simpler forms, non-harmful products will be released.

In this study, an innovative air cleaning system, named nano-confined catalytic oxidation (NCCO) system, was employed. The NCCO system consists of two compartments, namely, a zeolite chamber and an oxidant generating device. The zeolte chamber holds specially formulated nano-based zeolite, NaX for particular kinds of VOC removal while an oxidant generating device installed in the upstream location of the NCCO unit generates reactive oxygen species (ROS) (Daniel *et al.*, 2000). In the NCCO system, the zeolite secures the pollutants in its pores. This allows the ROS to interact with the pollutants and catalytically oxidize them into simpler components, such as CO_2 and H_2O, which are then released from the zeolite (Law *et al.*, 2003). In the case of ammonia, oxidization form of nitrogen, i.e., NO, NO_2, would be formed. In the presence of excess ROS would further oxidize the product into NO_3^-.

METHODOLOGY

The pilot test of using the NCCO air purification technology to remove the ammonia gas was carried out in a vacant office of 50 m^2. Five to ten units of air purifiers using NCCO air purification technology were mobilized to the office for use continuously during daytime and night-time. The units were operated over 5 days to cover the situation when the central A/C system of the office building was operated and shut down.

Two days before the units were operated and throughout the whole week of the testing period, the ammonia levels of the vacant office were measured by means of a photo-ionization detector (PID) (ppbRAE, Model: PGM-7240) and dragger tubes (Drägger range: 0.3–3 ppm.) PID measurement was conducted continuously during the first 4 days and once every hour during daytime for the remaining 3 days. In parallel, dragger tube testing was done once every 4 h during daytime for the whole week. During the ammonia testing in daytime, the indoor/outdoor temperature and relative humidity were monitored for reference. Ammonia tests using NIOSH Standard Method 6015 were conducted simultaneously by a local laboratory. The readings obtained by dragger tubes were compared to those obtained by NIOSH Standard Method 6015 (NIOSH, 1994).

As a control, the adjacent office of similar size and physical setting was selected to monitor the ammonia levels. The only difference for this control room was that there was no air purifier installed. Exactly the same testing protocol was done in this control room (Table 1).

RESULTS

Table 1 Summary of the results of the pilot test

Date	Time	Dragger tube results		Results from an independent PRC lab		Remark
		Test Office (with NCCO)	Control Office (without NCCO)	Test Office (with NCCO)	Control Office (without NCCO)	
2-9-2002	17:00	1.25	0.70	NA	NA	5 no. of NCCO trials operated overnight
	20:10	0.63	0.90	NA	NA	
3-9-2002	10:00	0.76	1.32	1.68	1.05	5 no. of NCCO were turned off at night
	12:00	1.04	0.42	1.53	1.13	
	16:00	0.90	0.28	1.52	0.93	
4-9-2002	09:00	0.70	0.56	1.21	1.06	5 no. of NCCO operated in daytime until 16:00 on 4-9-2002
	12:00	0.70	0.35	1.17	1.13	
	16:00	0.56	0.70	1.07	1.24	
5-9-2002	09:00	0.42	1.11	0.78	1.39	10 no. of NCCO operated continuously thereafter until the end of the test programme
	12:00	0.35	0.90	0.76	1.55	
	16:00	0.35	0.63	0.63	1.34	
6-9-2002	09:00	0.42	1.04	0.72	1.49	
	12:00	0.42	0.76	0.73	1.48	
	16:00	0.35	0.63	0.58	1.03	
7-9-2002	09:00	0.42	0.83	0.71	1.31	
	12:00	0.42	0.76	0.79	1.12	
	16:00	0.42	0.70	0.84	1.10	
8-9-2002	09:00	0.49	1.39	0.99	1.67	
	12:00	0.56	1.32	1.05	1.66	
	16:00	0.42	0.97	1.00	1.60	
9-9-2002	09:00	0.70	2.09	1.27	2.16	

Notes:

1. PRC: People's Republic of China.
2. From 2-9-2002 to 4-9-2002, fresh air supply was supplied to Control Office only, no fresh air supply to Test Office. There was no fresh supply to both Control Office and Test Office at night.
3. From 12:00 on 4-9-2002 and thereafter, fresh air supply was balanced to equally supply to the Control Office and Test Office. Fresh air supply was turned off at night.

Figures 1 and 2 show the graphs of the ammonia levels at the Control Office and Test Office corresponding to the results from Dragger Tube Testing and the PRC Laboratory, respectively.

Both the results from Dragger Tube testing and the PRC Laboratory using NIOSH method showed that the ammonia levels were much reduced when the NCCO were operated round the clock from the evening of 4 September 2002 onwards. This demonstrated that NCCO is effective in controlling ammonia levels in the Test Office. It was reported by the tenant that the ammonia level at the Test Office was around 3 mg/m^3 according to previous measurements. During the pilot test, however, the ammonia levels were below that level. In order to project whether the NCCO air purifiers can be used to control the ammonia level in the office building effectively, a mathematical model has to be developed such that the following design criteria would be applied:

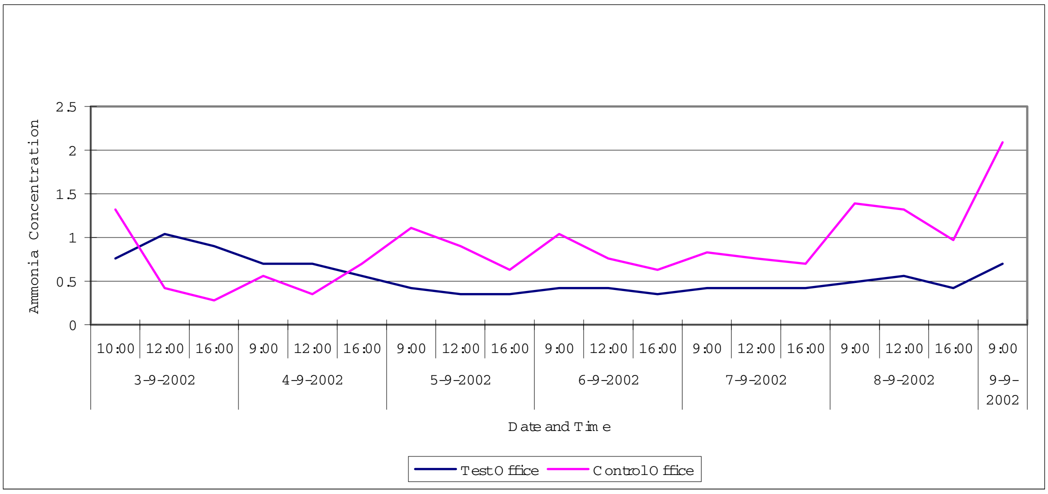

Figure 1 Monitoring of ammonia concentrations in the Test Office and Control Office (Dragger tube results).

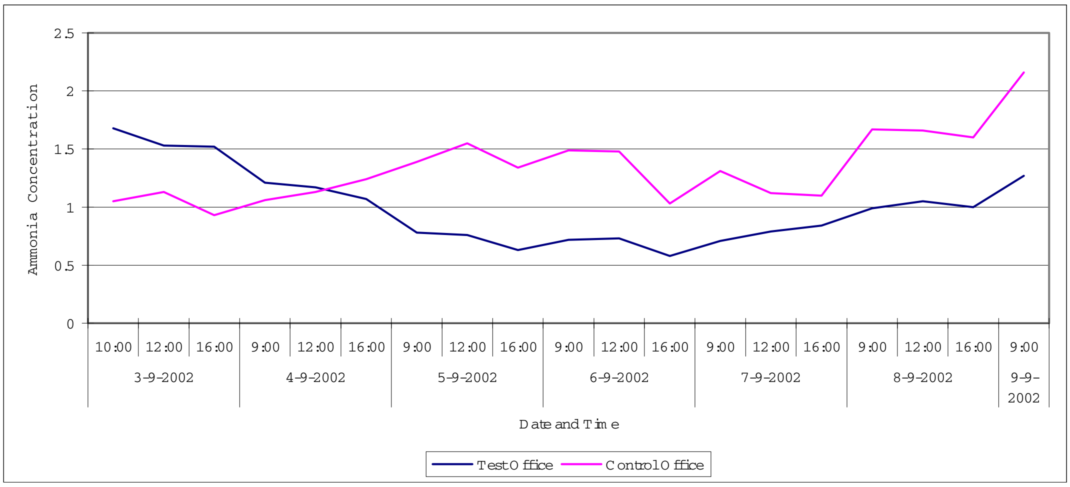

Figure 2 Monitoring of ammonia concentration in Test Office and Control Office (results from PRC laboratory).

Both the results from Dragger Tube testing and the PRC Laboratory using NIOSH method showed that the ammonia levels were much reduced when the NCCO were operated round the clock from the evening of 4th September 2002 onward. This demonstrated that NCCO is effective in controlling ammonia levels in the Test Office. It was reported by the tenant that the ammonia level at the Test Office was around 3 mg/m^3 according to previous measurements. During the pilot test, however, the ammonia levels were below that level. In order to project whether the NCCO air purifiers can be used to control the ammonia level in the office building effectively, a mathematical model has to be developed such that the following design criteria would be applied:

- Initial ammonia concentration: 3.5 mg/m^3 at 08:30 on a Monday morning
- Target concentration: 0.5 mg/m^3 during occupancy of the office (indoor air quality guideline in PRC for office premises)
- No change in air-conditioning system design.

$$V\frac{\mathrm{d}C}{\mathrm{d}t} = -Q(C - C_0) + E - R \qquad (1$$

where,

V = volume of the office (m^3), $V = 136.5m^3$
C = indoor concentration of ammonia (mg/m^3)
Q = fresh air supply rate to the office (m^3/h)
C_o = outdoor concentration of ammonia (mg/m^3), $C_o = 0.16$ mg/m^3
E = ammonia emission rate at office (mg/h)
R = ammonia removal rate by NCCO (mg/h)

$$R = k * C$$

where k is the ammonia removal efficiency of NCCO (m^3/h). (Note: k is indeed the multiplication product of the air flow capacity of the NCCO and the ammonia removal efficiency of the NCCO.)

Figure 3 shows the predicted change in ammonia levels over a week's time under different scenarios of NCCO operations as below:

- Scenario 1: NCCO being operated round the clock
- Scenario 2: NCCO operated during daytime but turned off at night
- NCCO not operated: No NCCO being operated under this scenario

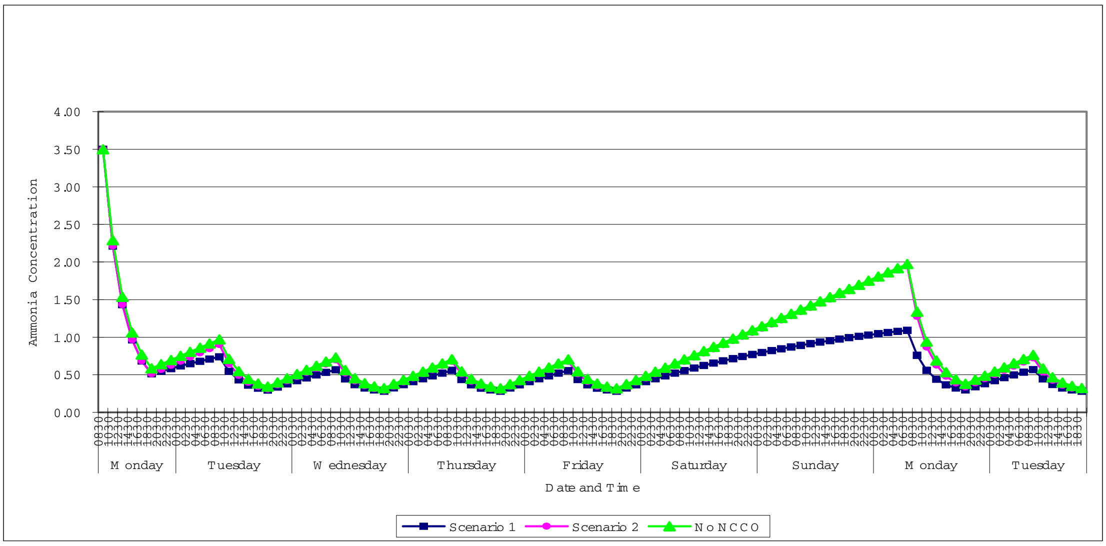

Figure 3 Predicted ammonia concentration under different scenarios of NCCO operation

The graphs demonstrate that ammonia levels can be properly controlled to below significantly low levels (0.5 mg/m^3) during occupancy under Scenario 1 even when the air-conditioning system is turned off over the weekend and Sunday. If air-conditioning system is turned on two to three hours earlier on Monday (i.e. at 06:00 instead of 08:30), the ammonia level can be controlled to below 0.5 mg/m^3 on Monday morning at around 08:30. With the existing fresh air supply rate of 32.1 m^3/h and NH_3 emission rate of 5.54 mg/h, air treatment rate of 6.62 mg/h by NCCO air cleaning device is need to be applied to keep the indoor NH_3 at low concentration.

DISCUSSION

Based on the findings and modelling in the previous sections, three feasible engineering solutions are proposed.

1. To maintain the ammonia level down around 0.5 mg/m^3 as indicated in the test, the indoor environment should be maintained at the current air change rate during the office hours with ceiling type NCCO devices operating over 24 h daily. The suggested number of ceiling type NCCO devices with air treatment rate of about 680 m^3/h is three units per 50 m^2.
2. The problem of excessive ammonia level can also be tackled by re-designing and installing a whole new air exhaust system that covers all compartments of the building. At

which, the return air would be treated by a central NCCO device before it is circulated back to the rooms.

The advantages and disadvantages of each method are discussed in Table 2.

Table 2 Pros and cons of proposed methods for ammonia control

Method	Pros	Cons
1	• Easy to install and maintain • Require no floor space • Evenly distributed for better treatment effectiveness • Can be installed in space only when it is occupied • Could slightly reduce the moisture level inside the premises and hence reduce the cooling load of the AC system	• Require larger number of units
2	• Centralized system is easy for maintenance • Induce better air change rate and hence require less powerful NCCO device	• Induce tremendous engineering works and disturbance to occupants • Less treatment effectiveness due to single end exhaust at each premises

CONCLUSIONS

In this study, it was found that without fresh air supply, the concentration of NH_3 could not be reduced to 0.5 mg/m^3 or close to this value. It was also proved by the fact that the concentration of NH_3 could be further reduced to 0.58 mg/m^3 when there was fresh air supply since 12:00 noon on 4 September 2002. With the existing fresh air supply rate of 32.1 m^3/h and NH_3 emission rate of 5.54 mg/h, air treatment rate of 6.62 mg/h by NCCO air cleaning device is need to be applied to keep the indoor NH_3 at low concentration. From the results of the modelling, if NCCO air cleaners are not used at night-time, the increase of ammonia concentration is larger than the case in which air cleaners are used. Hence, the time taken to reduce NH_3 to a low level in the following morning is longer. Three methods are proposed for ammonia control. They are (i) ceiling type NCCO devices, (ii) modular cabinet type NCCO device, and (iii) new air exhaust system with a central NCCO device installed at each plant room. The pros and cons of each method were also evaluated.

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