NUMERICAL VALUE RESEARCH ON BAKE-OUT TECHNOLOGY WITH DILUTION VENTILATION FOR BUILDING MATERIALS

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ABSTRACT

Bake-out with dilution ventilation is a potential technology that can shorten emission cycle of indoor VOCs and other hazardous gas, and then reduce indoor environment pollution brought forward by building materials. This technology based on characteristic that chemical substance of building materials is easier to emit under high temperature. This paper used numerical value method to compute TVOC removal amount under different operation conditions and concentration changes indoor during bake-out exhaust dilution process. Except that, this paper also discussed effects of bake-out temperature, bake-out time, ventilation time, air change rate on removal.

KEYWORDS

Building Materials, Contamination Emission Model, Bake-out Exhaust Dilution, Total Volatile Organic Compounds

INTRODUCTION

In China, with the improvement of the living standard and civil building innovation, large numbers of building materials and decorated materials have been used. Some kinds of VOCs like Formaldehyde, benzene, toluene and xylene etc. released from these materials make up the main indoor pollution source and impact people's health so much. In China, adult spend 80-90% of his time indoors, while for old man and baby, the time inside buildings even increase to more than 95%. Indoor air pollution has been listed into one of five environment factors which damage mankind's health most. After "soft coal pollution" and "photochemistry fog pollution" brought by industrial revolution, China now has entered the third pollution period which sign "indoor air pollution". Deleterious gas release from building materials is thought to be the main reason. In Beijing, indoor environment pollution induced by decoration has become one of five issues. According to investigation of Chinese indoor decoration union indoor pollution inspect center, deleterious materials account for 68% of decorated materials and bring 300 kinds of VOCs and induce 30 kinds of diseases. Some resources unveiled that only in Beijing, acute poisoning accident from decorative building material was about 400 with 10,000 people involved and caused nearly 350 deaths every year, the casualty of chronicle poisoning was much more From the above, we can find indoor environment pollution in developing countries is very serious and do great damage to health and economy development.

From the 1st Indoor Air Quality and Climate International Conference in 1974, strategies for effectively controlling indoor pollution from building materials have been widely applied. Many studies have shown that emission rate of formaldehyde and VOCs have close relationship with temperature. Renata Wiglusz found that temperature has a significant influence on the emission rate of VOCs, especially under higher temperature. Other researches used other materials and obtained the same results. Based on the volatile characteristics mentioned before, bake-out method is widely applied, especially USA and Japan.

It is well know that the construction details and building materials used in China are very different with developed countries. In order to discuss the potential of this technology in China, the performance of this technology is analyzed detailedly by experimental and numerical methods.

1 Numerical value revolution

1.1 Model development

Although the bake-out effect can be detected by experiments mentioned before, such studies are costly, time-consuming, and difficult to scale-up the measured data from a small environmental chamber to a real building. Therefore, it is necessary to develop a mathematical model to predict or estimate the bake-out effect. In this study, only TVOC was used as model pollutant. The emission rate of TVOC from the indoor materials was calculated using the following simple model:

$$E(t) = -D_c \left.\frac{\partial C}{\partial x}\right|_B = -D_c \frac{\partial C(0,t)}{\partial x} = \frac{2D_c C_0}{L}\sum_{n=1}^{\infty}\exp\left[-D_c\left\{\frac{(2n-1)\pi}{2L}\right\}^2 t\right] \quad -(1)$$

where $E(t)$ is the emission rate of TVOC [mg/(s · m^2)]; D_c is effective diffusion coefficient of TVOC (m^2/s); t is time (s); L is the thickness of material (in this paper L=0.006m).

The corresponding TVOC concentration within the material is given as:

$$C(x,t) = \frac{4C_0}{\pi}\sum_{n=1}^{\infty}\frac{1}{(2n-1)}\cdot\exp\left[-D_c\left\{\frac{(2n-1)\pi}{2L}\right\}^2 t\right]\sin\frac{(2n-1)\pi}{2L}x \quad -（2）$$

where C is the TVOC concentration within the material (mg/m^3); C_0 is the initial TVOC concentration (in this paper, $C_0 = 1.92\times10^{-5}$mg/m^3);

The transient TVOC mass balance in the room can be expressed by

$$\frac{dC_r}{dt} = \frac{Q}{V}(C_{in} - C_r) + \frac{M}{V} \qquad -\ (3)$$

where C_r is the indoor TVOC concentration (mg/m^3); C_{in} is the outdoor TVOC concentration (mg/m^3); Q is the ventilation rate (m^3/s); V: is the volume of the room (m^3); M is the emission rate of TVOC (mg s-1), which is given:

$$M = A \cdot E(t) \qquad -(4)$$

where A is the area of building material (m^2).

The formula above suppose x axis is vertical to the surface of material and effective diffusion coefficient calculated from Arrhenius equation.

$$D_c = D_{ref} \exp\left[-E\left(\frac{1}{T} - \frac{1}{296} \right) \right] \qquad -\ (5)$$

According to Arrhenius equation, effective diffusion coefficient has close relationship with temperature. In here, D_{ref} as effective diffusion coefficient in 23℃ (296K), T as absolute temperature (K), E=17200 (K) as experimental coefficient.

1.2 Model validation

In order to verify the aforementioned model, the predicted benzene concentrations based on the model are compared with experimental data (case4). As shown in Figure 1, there is good agreement between the measured and calculated concentrations. The minor discrepancies may be due to instability and partial mixing in the chamber.

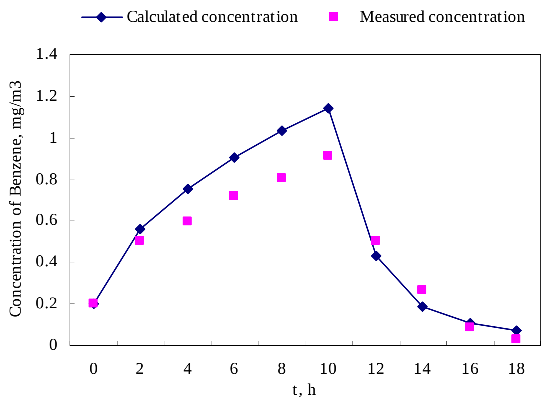

Fig.1 Comparison of measured and calculated benzene concentrations

1.3 Simulation conditions

The range of measured indoor concentrations of different VOCs is extremely wide. Wang found that the TVOC concentrations ranged from 0.213 to 28.326mg/m^3 in Harbin dwellings. Therefore the initial TVOC concentration was set as 8.027 mg/m^3. In addition, the size of room for bake-out was assumed as 20m^2 and 60m^3.

Factors such as baking time, baking temperature, ventilation time and air change rate were used for parametric study. In this study, index of N_r was introduced to estimate the elimination capacity. As shown in Figure 2, The shadow part in Figure 8 multiply ventilation rate means N_r in course of bake-out. In addition, nondimensional N_r and nondimensional concentration are used in later text.

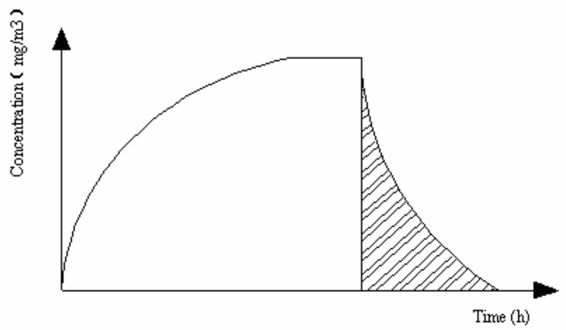

Fig.2 Schematic of elimination capacity Nr

2 Simulation Results

2.1 Effect of baking temperature

Because of different D_c under different temperature, baking temperature take great effect on TVOC emission. In this study, basis condition was determined as ventilation for 4 h after bake-out for 5 h and air change rate was assumed as 0.6h^{-1}. baking temperature is set at 30、35、40 and 45^{o}C, and consider that woodwork maybe distorted after baking in high temperature, the temperature was controled under 45^{o}C.

Figure 3 shows dimensionless removal content of TVOC under various baking temperature. From the figure, we can find that removal content of TVOC is 1.09, 1.19, 1.35 and 1.60 times respectively under 30,35,40 and 45^{o}C when compared with that under 23^{o}C. So it is clearly that removal content of TVOC increase with increase of baking temperature. The main reason is that D_c is 3.83, 9.62, 23.48, 55.7 times compared with that under 23^{o}C respectively. Figure 4 shows nondimensional concentration of TVOC change with time. We can find concentration increase with increase of baking temperature and arrives at 1.78 times under 45^{o}C compared with initial concentration, but decrease to lower than initial concentration after intermittent ventilation. This proves that ventilation dilution can speed TVOC emission and shorten emission period.

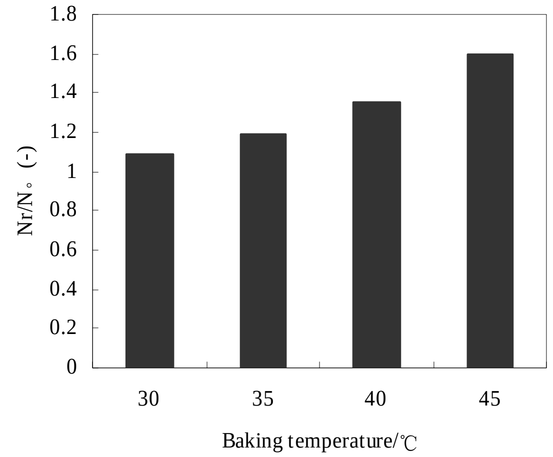

Fig.3 Dimensionless elimination capacity of TVOC under different baking temperatures

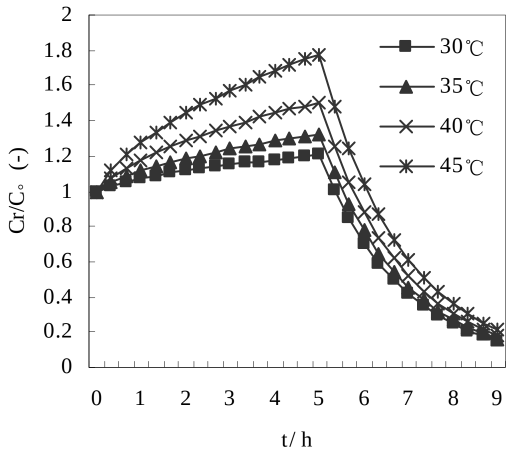

Fig.4 Dimensionless concentration of TVOC under different baking temperatures

2.2 Effect of ventilation rate

It is supposed baking 5 hours under 40^{o}C and ventilation for 4 h, change ACH as 0.6, 3, 6, 12 and 30h^{-1} respectively. Figure 5 shows dimensionless removal content of TVOC under different ACH. It is found that dimensionless elimination capacity of TVOC increase with increase of air change rate, and arrives at 8.21 times when ACH changer from 0.6/h to 30/h. Figure 6 shows ventilation 4 hours is enough to decrease indoor TVOC concentration to a lower level after baking, and it is sooner if ACH is higher. When air change rate arrives at 6h^{-1}, 3 hours is enough and indoor TVOC concentration will not change with ACH increase.

In all, ventilation after baking take a great role on decreasing indoor TVOC concentration and removing pollutant, but considering energy saving 3/h will be the best if ventilation more than 4 hours.

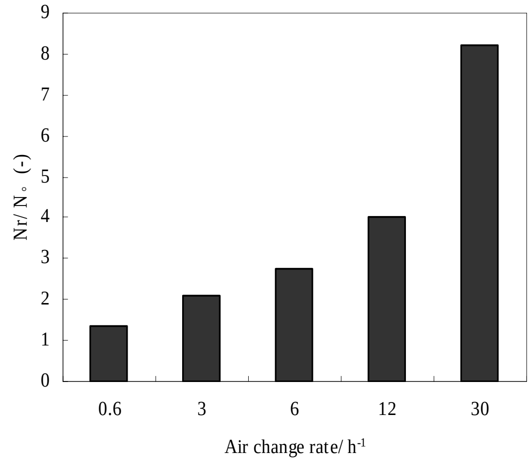

Fig.5 Dimensionless elimination capacity of TVOC under different air change rates

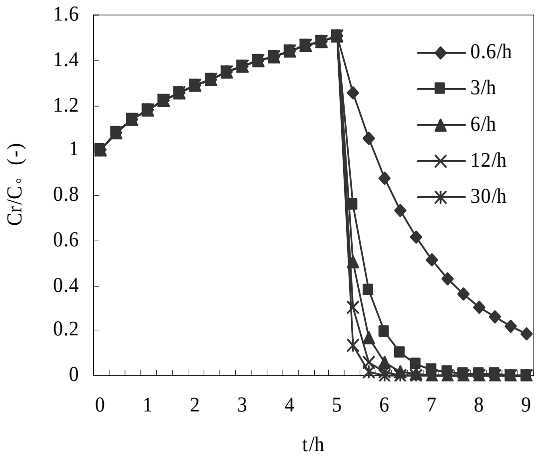

Fig.6 Dimensionless concentration of TVOC under different air change rates

2.3 Effect of baking and ventilation time

Considering it may do damage to building material if baking time is too long, so based on experiment result of Nozaki et al, the following three cases were chosen to study effect of baking and ventilation time:

Case 1: ventilation 4 hours after baking 5 hours,

Case 2: ventilation 4 hours after baking 10 hours,

Case 3: ventilation 8 hours after baking 10 hours.

As shown in Figures 7, 8, 9, it can be found that elimination capacity of TVOC increases due to a longer baking and ventilation timegenerally. Compared Figure 7 to 8, it is clearly longer baking time, higher baking temperature and higher ACH can increase removal content of TVOC more effectively. While compared Figure 8 to 9, find that it is not effective when lengthen ventilation time after ACH is higher than 3h^{-1} and baking time is longer than 4 hours. Compared 7 with 9, removal content of TVOC of case 1 is higher than that of case 3.

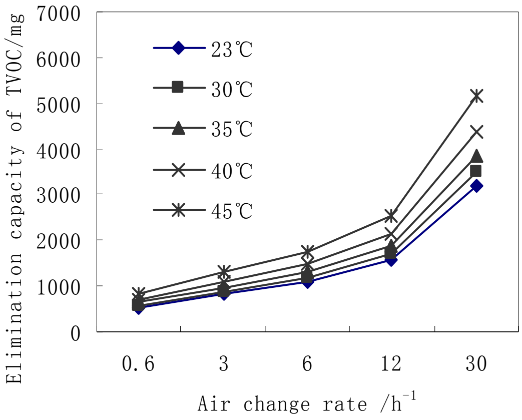

Fig.7 Elimination capacity of TVOC (Case 1)

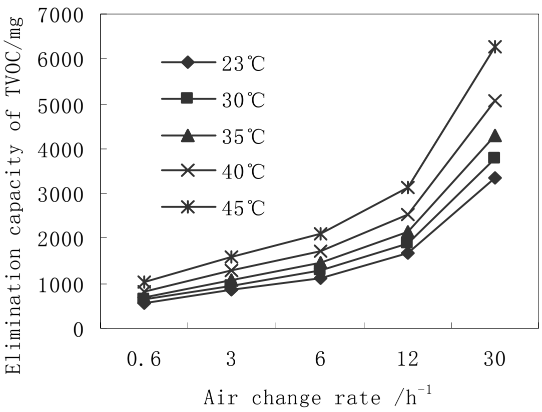

Fig.8 Elimination capacity of TVOC (Case2)

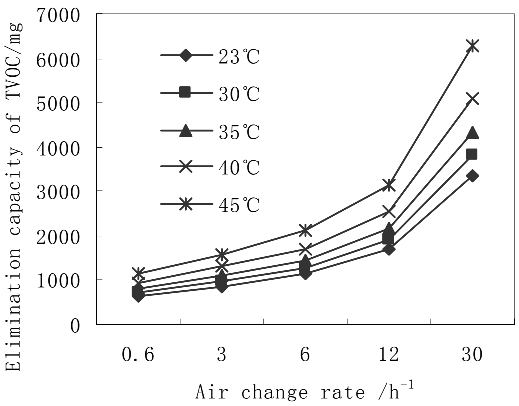

Fig.9 Elimination capacity of TVOC (Case 3)

3 Conclusions

This paper studies bake-out exhaust dilution technology from building materials mainly, based on combining a chamber test with numerical simulation to simulate newly decorated house in China. TVOC are the main study object. Removal content of TVOC and concentration variety is studied under different baking time, baking temperature and ACH, conclusions as follows:

1. From numerical simulation, we can find that increase baking temperature, ACH, baking time and ventilation time can increase Removal content of VOCs, but these factors take different role. Because of different D_c under different temperature

2. With increase of baking temperature, Removal content of TVOC increase. Because of different D_c under different temperature, this content increase by degrees.

3. With increase of ACH, Removal content of TVOC increase. When initial concentration is lower than 8.027 mg/m^3, it is more reasonable to choose 3/h if ventilation 4 hours.

4. Lengthen baking time, ventilation time can increase Removal content of VOCs. It is not effective when lengthen ventilation time after ACH is higher than 3/h and baking time is longer than 4 hours.

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REFERENCES

Jiang Anxi. 2003. Air pollution control [M]. Beijing: chemical industry press. 232.

Wu Qi. 2001. Volatile organic compounds pollution [J]. Chemical teaching, 7:17-18.

Zen Yanjun, Su Xing. 2001. Investigation of Indoor Air Pollution [J]. Environment Supervise Management and Technology, 13(6):15-17.

Xin Shangjie, Cheng Baoying, Zhu Peigen. 2002. Quantitative evaluation of VOC in Indoor Air [J]. HV&AC, 32(3):34–35.

Guo H, Murray F. 2000. Characterization of total volatile organic compound emissions from paints [J]. Clean Product and Processes.l2: 28–36.

Wiglusz R,Sitko E, Nikel G et al. 2002. The effect of temperature on the emission of formaldehyde and volatile organic compounds from laminate flooring-case study [J]. Building and environment. 37:41-44.

Zhou Dingguo, Han Shuguang. 1997. Effect of temperature on emission of formaldehyde from flakeboard [J]. Architecture manmade plane, (4):3-8.

Bai Yanbin, Liu Xingrong. 2003. Effect of Temperature in Simulation Chamber on Emission of Formaldehyde [J]. Chin J Public Health, 19(5):577-578.

Nozaki A, Iikura K, Yoshizawa S et al. 2000. Effects of bake out as a source control technique for indoor chemical substances (part1) [J]. J. Archit. Plann. Environ. Eng.,AIJ, 530:61-66.

Nozaki A. 2000. Study on strategies for indoor pollution prevention (Part 1) Bake-out for indoor VOC prevention [J]. J. of SHASE, 1:13-20.

Kumano. 1999. Effect of bake-out applied to apartment building with natural ventilation on descending VOCs[C]. Academy of Indoor Environment, Japan: 114-115.

Yang Xudong, Chen Qingyan. 1998. Bluyssen P M.

Prediction of short-term and long-term volatile organic compound emissions from SBR bitumen-backed carpet under different temperatures[J], ASHRAE Transactions, 104(2), 1297-1308.

Kondo Y, Kato S, Mulakami S et al. 1999. Physical model and numerical analysis of VOCS emission from building materials (part2) prediction of short term and long term VOCS emission based on micro-macro model [C]. Summaries of Technical Papers of Annual Convention Architectural Institute of Japan, China : 123～124.

Kondo Y, Kato S, Mulakami S et al. 1999. Physical model and numerical analysis of VOCS emission from building materials (part3) prediction of short term and long term VOCS emission based on micro-macro model [C]. Summaries of Technical Papers of Annual Convention Architectural Institute of Japan, China : 125～126.

Li jing, Liu Jing, Lu Yang et al. 2005. Improve of IAQ by a new bake-out method based on chamber tests [C]. The 10th international Conference on Indoor Air Quality and climate,Beijing: 3075-3079.

Wang Kun. 2004. Study of indoor air pollutant detection , forecast and control [D]. Harbin. Harbin institute of technology.

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