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Trace Amount Formaldehyde Gas Detection for Indoor Air Quality Monitoring

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Abstract— Formaldehyde is not only a carcinogenic chemical, but also causes sick building syndrome. Very small amounts of formaldehyde, such as those emitted from building materials and furniture, pose great concerns for human health. A Health Canada guideline, proposed in 2005, set the maximum formaldehyde concentration for long term exposure (8-hours averaged) as 40 ppb ($50 \mu\text{g}/\text{m}^3$). This is a low concentration that commercially available formaldehyde sensors have great difficulty to detect both accurately and continuously. In this paper, we report a formaldehyde gas detection system which is capable of pre-concentrating formaldehyde gas using absorbent, and subsequently thermally desorbing the concentrated gas for detection by the electrochemical sensor. Initial results show that the system is able to detect formaldehyde gas at the ppb level, thus making it feasible to detect trace amount of formaldehyde in indoor environments.

Keywords—formaldehyde; sensor; pre-concentrator; indoor air quality monitoring

I. INTRODUCTION

Formaldehyde is a common pollutant in indoor air [1-4]. It mainly comes from two sources. The first one is the emissions from building materials and furniture; such as the pressed wood products that use adhesives containing formaldehyde; adhesives; floor finishings; paints; wall papers, varnishes and etc. The other source is from the burning of materials, for example smoking. Health Canada report [1] shows long-term exposure may result in respiratory symptoms such as coughing and wheezing, and allergic sensitivity, especially in children. The risk of irritation or burning sensation in eyes, nose and throat from short-term exposure grows with increasing concentration. There is also an increased likelihood of respiratory symptoms from long-term exposure. It is reported that there is a significant positive association between formaldehyde exposure and childhood asthma [5]. In addition, formaldehyde is considered as a carcinogenic gas [6, 7]. Health Canada guideline [1] for short-term (1-hour averaged) exposure of formaldehyde is $123 \mu\text{g}/\text{m}^3$ (100 ppb) and for long-term (8-hours averaged) exposure is $50 \mu\text{g}/\text{m}^3$ (40 ppb). Although formaldehyde concentration in majority of

residential homes in Canada and France are within those exposure limits, recent reports [2, 3] in both France and Canada show that some homes have formaldehyde concentration over the long-term exposure guideline. For example, studies made by Health Canada scientists show that formaldehyde concentrations in residential indoor air in Prince Edward Island, Canada is between 5.5 to $87.5 \mu\text{g}/\text{m}^3$ (4.4 to 70 ppb). Formaldehyde detection is normally done by sample collection on-site and analyses in a laboratory. This is a very time consuming process and not suitable for on-site formaldehyde monitoring. Currently, several types of formaldehyde sensors, including photoelectric [8-9], electrochemical based devices are commercially available. The majority of them target ppm level formaldehyde gas detection and are not suitable for indoor air quality monitoring. A few commercial off-the-shelf sensors are capable of sensing formaldehyde at tens of ppb concentrations, but they are not suitable for continuously monitoring. Most of those sensors have been evaluated in our labs. But their resolution and accuracy are not good enough for continuous indoor air quality monitoring. In recent years, many research groups are addressing this issue using different approaches [10-14]. Nevertheless, achieving the ppb detection level still seems a daunting task. In this work, we proposed a pre-concentrator based sensing system to significantly improve the detection level of formaldehyde gas. Some initial results are presented in this paper.

II. OPERATION PRINCIPLE AND EXPERIMENTAL

Formaldehyde is a low molecular weight organic gas/vapor. It is very difficult to be directly concentrated using approaches based on solid phase. The general practice is using solutions to trap and concentrate formaldehyde and in the mean time convert it to another chemical in solution prior detection. This is an irreversible process and not suitable for continuous indoor air quality monitoring applications. In this work, we propose to use a solid trap/thermal desorption based pre-concentration system for the pre-concentration of formaldehyde gas. This system offers the advantages as:

- Continuous operation
- High theoretical pre-concentration factor

- Simple
- Gas/solid phase (no liquids are required)
- Design versatility

Fig. 1 shows the schematic illustration of the system setup. It mainly consists of a pre-concentrator, a Membrapor electrochemical formaldehyde sensor, a temperature controlling unit, solenoid valves, a flow meter and the circuits boards (not shown) for the control of the detection system.

Fig. 1 Illustration of the pre-concentrator based formaldehyde detection system

The pre-concentrator was made of a glass tube with a ~6 mm diameter and 35 mm length. 170 mg of absorbent was packed in the middle of the tube. Glass wool was placed at both sides of the absorbent to stop its moving inside in the tube (as illustrated in Fig. 2). A Nichrome heating wire was wrapped around the tube to cover the length of the absorbent. The heater was connected to a solid-state relay operated by a temperature controller. A J-type thermocouple was inserted into the absorbent to monitor the temperature inside the absorbent. This heating system can heat the absorbent to more than 150°C in less than 30 seconds, and to more than 350°C in three minutes. A computer fan was placed in close proximity to the pre-concentrator to accelerate the cooling process.

The proposed system operates in three steps:

Step 1 absorption. Valves 3, 4 and 5 are open. The pump pulls the testing gas into the pre-concentrator in the absorption direction for the required period of time. Formaldehyde gas going through the absorbent is trapped/absorbed, while normal air passes through the absorbent as illustrated in Fig. 2.

Fig. 2 Mechanism of pre-concentrator operation

Step 2 desorption. Valves enabling the absorption are closed. The pre-concentration tube is heated to a temperature of ~150°C to release the formaldehyde collected by the absorbent. Then the valves (valves 1, 2 and 6) controlling the desorption flow are open and enable the sensor to detect the concentrated formaldehyde gas.

Step 3 Conditioning of the pre-concentration tube. The tube is cooled to room temperature for the next formaldehyde testing cycle. If it is needed, the tube can be heated to high temperature, such as 350°C, to clean the absorbent.

III. RESULTS AND DISCUSSIONS

A. Absorbent performance

Fig. 3 presents the absorption capacity testing results. Detection is accomplished with a Z-300XP formaldehyde sensor (an electrochemical type sensor) from Environmental Sensors Co. Absorption of formaldehyde gas was performed with 170 mg of absorbent (proprietary information). Testing experiments were carried out with 700 ppb formaldehyde in nitrogen. The y-axis represents the concentration of formaldehyde not captured by the absorbent. The results show that within 350 seconds, close to 100% of formaldehyde is absorbed by the absorbent. After this period of time, formaldehyde starts to break through the absorbent. The absorbent's capacity for absorbing formaldehyde without breakthrough is calculated as ~0.012 µg/mg. With this number, a pre-concentrator detailed in the last section was designed.

Fig. 3 Absorption capacity testing results

B. System performance

Fig. 4 presents the results of the pre-concentrator operating with the formaldehyde detection system as illustrated in Fig. 1. The results clearly show that the pre-concentrator significantly improves the detectability of formaldehyde. The concentration factor increases with the decrease of the formaldehyde concentration. A concentration factor of more than 40 times has been achieved when sampling formaldehyde at concentrations lower than 170 ppb. It should be noted that the Membrapor electrochemical transducer in the absence of the pre-concentrator could not give a reliable reading when the formaldehyde concentration is 10 ppb. This is consistent with all the commercial off-the-shelf sensors we have evaluated in our laboratories. However, our pre-concentrator effectively increases the gas concentration to 776 ppb under the same experimental condition and this yields a more reliable measurement.

Fig. 4 Concentration effect of the pre-concentrator based formaldehyde detection system (15 minutes absorption time)

We have checked the relationship between the concentration and the absorption time. Fig. 5 shows the results when sampling formaldehyde at 70 ppb. As it can be seen, the concentration factor increases linearly with the absorption time when the absorption time is less than 15 min suggesting that the concentration factor can be easily adjusted if needed by controlling the absorption time.

Fig. 5 Effect of absorption time on the concentration factor (70 ppb formaldehyde in dry nitrogen)

The repeatability of the system was also tested. Some results are shown in Fig. 6. The concentration factor at the same conditions were tested in two consecutive days and the results were the same, thus proving the repeatability of the system.

Fig. 6 Repeatability test of the pre-concentrator based formaldehyde detection system (70 ppb formaldehyde source)

IV. CONCLUSIONS

We have successfully developed a prototype for a pre-concentrator for the detection of trace amounts of formaldehyde. The concentration factor increases as the formaldehyde concentration decreases. The factor is greater than 40 times when the formaldehyde concentration is less than 100 ppb. This makes the detection of trace amount of formaldehyde in indoor environments feasible when combining our pre-concentrator with most of the commercial available sensors.

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REFERENCES

- [1] "Residential Indoor Air Quality Guideline—Formaldehyde ", http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/formaldehyde-eng.pdf
- [2] C. Marchand, S. Le Calve, Ph. Mirabel, N. Glasser, A. Casset, N. Schneider, and F. de Blay, "Concentrations and Determinants of Gaseous Aldehydes in 162 Homes in Strasbourg (France)", *Atmospheric Environment*, vol. 42, pp. 505-516, 2008
- [3] N. L. Gilbert, M. Guay, J. D. Miller, S. Judek, C. C. Chan, and R. E. Dales, "Levels and Determinants of Formaldehyde, Acetaldehyde, and Acrolein in Residential Indoor Air in Prince Edward Island, Canada", *Environmental Research*, vol. 99, pp. 11-17, 2005
- [4] M. R. Dudzinska, A. Staszowska, and B. Polednik, "Preliminary Study of Effect of Furniture and Finishing Materials on Formaldehyde Concentration in Office Rooms", *Environment Protection Engineering*, vol. 35, pp. 225-233, 2009
- [5] G. McGwin Jr., J. Lienert, and J. I. Kennedy Jr., "Formaldehyde Exposure and Asthma in Children: Systematic Review", *Environmental Health Perspectives*, vol. 118, pp. 313-317, 2010

- [6] "Formaldehyde and Cancer Risk", <http://www.cancer.gov/cancertopics/factsheet/Risk/formaldehyde>
- [7] "Formaldehyde", <http://www.cdc.gov/niosh/idlh/50000.html>
- [8] Y. Suzuki, N. Nakano, and K. Suzuki, "Portable Sick House Syndrome Gas Monitoring System Based on Novel Colorimetric Reagents for the Highly Selective and Sensitive Detection of Formaldehyde", *Environmental Science & Technology*, vol. 37, pp. 5695-5700, 2005
- [9] K. Kawamura, K. Kerman, M. Fujihara, N. Nagatani, T. Hashiba, and E. Tamiya, "Development of a Novel Hand-Held Formaldehyde Gas Sensor for The Rapid Detection of Sick Building Syndrome", *Sensors and Actuators B*, vol. 105, pp. 495-501, 2005
- [10] K. Toda, K-I Yoshioka, K. Mori, and S. Hirata, "Portable System for Near-Real Time Measurement of Gaseous Formaldehyde by Means of Parallel Scrubber Stopped-Flow Absorptionmetry", *Analytica Chimica Acta*, vol. 531, pp. 41-49, 2005
- [11] W. Zeng, T. Liu, Z. Wang, S. Tsukimoto, M. Saito, and Y. Ikuhara, "Selective Detection of Formaldehyde Gas Using a Cd-Doped TiO₂-SnO₂ Sensor", *Sensors*, vol. 9, pp. 9029-9038, 2009
- [12] Q. Ma, H. Cui, and X. Su, "Highly Sensitive Gaseous Formaldehyde Sensor with CdTe Quantum Dots Multilayer Films", *Biosensors and Bioelectronics*, vol. 25, pp. 839-844, 2009
- [13] S. Li, F. Li, and Z. Rao, "A Novel and Sensitive Formaldehyde Gas Sensor Utilizing Thermal Desorption Coupled with Cataluminescence", *Sensors and Actuators B: Chemical*, vol. 145, pp. 78-83, 2010
- [14] L. Feng, C. J. Musto, and K. S. Suslick, "A Simple and Highly Sensitive Colorimetric Detection Method for Gaseous Formaldehyde", *Journal of American Chemical Society*, vol. 132, pp. 4046-4047, 2010