Emission Characteristics of Formaldehyde from Natural Gas Combustion and Effects of Hood Exhaust in Chinese Kitchens

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Abstract. Formaldehyde (HCHO) is a well known carcinogen. While most studies investigate emission from wood-based materials, knowledge about releasing of HCHO by natural gas combustion is quite limited. This study conducted field measurements in 9 households to address this issue. Formaldehyde generated by natural gas combustion in kitchens can quickly disperse to an adjacent living room when kitchen door is open. A range hood can effectively remove formaldehyde in kitchens if kitchen window is open and kitchen door is closed. Its performance would decrease by half otherwise. These results imply a health co-benefit of reducing household usage of carbon-based natural gas in the age of carbon neutrality aiming climate change.

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1 Introduction

World Health Organization confirmed formaldehyde (HCHO) in the air as a Group 1 human carcinogen in 2004[1]. This is followed by European Commission to classify HCHO as a 1B carcinogen and mutagen in 2014 [2]. It is one of the most important air pollutants [3, 4].

Natural gas combustion has been recognized to emit formaldehyde [5]. Research has been done to elucidate formation mechanism of formaldehyde by natural gas combustion[6, 7]. Currently, natural gas is a fuel used in residence widely in China, implying that formaldehyde emitted by incomplete combustion of natural gas could pose adverse health effects to a wide population. In 2019, consumption of natural gas for residential use reached 46.8 billion m3, and there are 390 million urban residence using natural gas as residential fuel [8]. A recent survey revealed that 67% of Chinese families use natural gas as their primary cooking energy[9]. In addition, natural gas is also used broadly in residences all over the world. For example, 34% of American households use natural gas as their primary cooking fuel [5], and this number increases to more than 80% in Tehran, Iran [10].

The present study aims to investigate effect of hood ventilation in diluting indoor formaldehyde concentration. Results reported here can be used to support exposure assessment and engineering control of indoor formaldehyde from natural gas combustion.

2 Introduction

2.1 Methodology

Nine family kitchens (area between 4 and 24 m^2) in Nanjing were chosen as the sampling sites. There are five different brands of gas stoves, all using natural gas as the cooking fuel. In our study, water was burnt to avoid formaldehyde emission from food material and oil. The sampling point was placed with a height of 1.2m uniformly, 0.3-0.5m away from the gas stove.

2.2 Sample analysis

In this study, 3-methyl-2-benzothia-zolinone hydrazone (MBTH) and 4-amino-3-hydrazino-5-mercapto-1,2,4-triazole (AHMT) spectrophotometric methods were used to measure formaldehyde concentration, in accordance with the Chinese national method[11]. The average of the two method measurements was used as the kitchen formaldehyde concentration to make the data more credible.

For the MBTH method, indoor air were pumped into a glass sampling tube using a QC-2A pump at a flow rate of 300 mL/min. Formaldehyde would be absorbed in the phenol reagent. The sampling time was 10 min. To analyze the formaldehyde concentration, we added 0.4 mL of 10g/L ferric ammonium sulfate solution into the samples. After the samples had been held for 15 min, the light absorbance was measured using a spectrophotometer at 630 nm. A calibration curve with R^2 of 0.9994 was established to quantify formaldehyde amount. The detection limit of formaldehyde was 0.02μg and the recovery of formaldehyde was 90-105%[12]. At least one blank sample should be set for each group during the same sampling period. The accuracy of this method was analyzed in detail by Chan et al. [13] with satisfactory results. Liang et al. [14] also observed strong correlation between HPLC and MBTH (R^2>0.997) , and the relative standard deviations between these two methods were <15%.

For the AHMT method, indoor air samples were pumped into a glass sampling tube using a QC-2A pump at a flow rate of 1000 mL/min. The sampling time was 10 min. To analyze the formaldehyde concentration, we added 1.0 mL of 5mol/L potassium hydroxide solution and 1.0 mL of 0.5% AHMT solution into the samples. After the samples had been held for 20 min, add the 0.3mL of 1.5%potassium periodate solution. Wait 5 min after shaking the solution fully, the light absorbance was measured using a spectrophotometer at 550 nm. A calibration curve with R^2 of 0.9991 was established to quantify formaldehyde amount. The detection limit of formaldehyde was 0.13μg and the recovery of formaldehyde was 93-99%. At least one blank sample should be set for each group during the same sampling period. R.G. Dickinson et al. [15] confirmed AHMT is a well-described reagent with a high sensitivity and selectivity towards HCHO.

3 Results

3.1 Effect of range hood exhaust

A range hood is usually the primary strategy to mitigate exposure to pollutants from cooking [16]. We examined its effects during natural gas combustion, as presented in Figure 1. Formaldehyde concentration decreased by 63% on average (52%-77%), calculated as the difference between before and after a range hood was turn on. These results indicate that use of range hood can yield quick and substantial reductions in kitchen when kitchen door is closed.

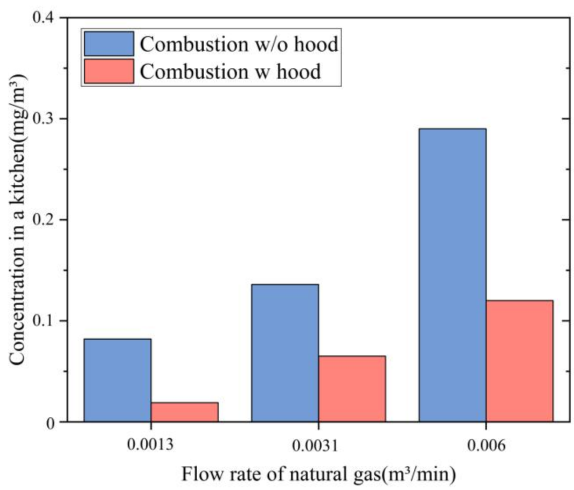

Fig. 1. Effects of range hood on formaldehyde concentration in a kitchen. Kitchen door is kept closed. Kitchen window was closed for combustion w/o range hood (10 minutes) condition and turn open for combustion w/ range hood (10 minutes).

The effect of range hood is subject to status of kitchen door and window. When kitchen door was open, removal effect of range hood was significantly reduced, as show in Figure 2. In case 1, kitchen door was kept open. After 20 minutes of natural gas burning with kitchen window closed, formaldehyde concentration increased to 0.103 mg/m^3 in the kitchen. Range hood was then turn on, kitchen window was open, and kitchen door remained open. The formaldehyde concentration decreased to 0.072 mg/m^3 in 10 minutes in the kitchen. This reduction of 30% is significantly lower than that with kitchen door closed (63% on average). It is because that with kitchen door and window open, outdoor air and polluted air in the living room might both be sucked into the kitchen by the range hood, leading to a less efficient removal of the range hood than that with only outdoor air in when kitchen door was closed. The formaldehyde concentration in the living room even remained almost unchanged (0.091 mg/m^3 and 0.092 mg/m^3 in the 10-20 min and 20-30 min, respectively). It might take longer time and/or need fresh supply air from other spaces of the apartment to dilute formaldehyde in the living room by the range hood.

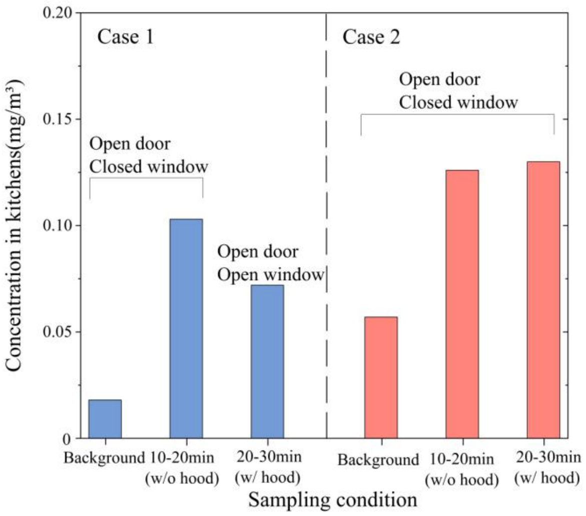

Fig. 2. Effects of kitchen door and window on performance of range hood in a kitchen. Case 1: Kitchen door is open. Kitchen window was closed for combustion w/o range hood (10-20 min) and turn open for combustion w/ range hood (20-30 min). Flow rate of natural gas is 4.7 L/min. Case 2: Kitchen door is open. Kitchen window was closed for both combustion w/o range hood (10-20 min) and combustion w/ range hood (20-30 min). Flow rate of natural gas is 5.3 L/min.

Kitchen window also exhibited influence on effect of the range hood, as illustrated in case 2 in Figure 2. Kitchen window was closed and kitchen door was open throughout the test. After the range hood was turn on, formaldehyde concentrations in the kitchen was not reduced (0.126 mg/m^3 Vs 0.130 mg/m^3). So is that in the living room (0.115 mg/m^3 Vs 0.117 mg/m^3). This is because that a limited amount of fresh outdoor air was available to dilute formaldehyde concentration as kitchen window was closed [17]. Combining results above together, an effective way to reduce formaldehyde concentrations in a kitchen and living room should be to keep kitchen door closed, turn on range hood, and keep kitchen window open. If outdoor environment condition is not favorable for opening window, then a make-up air system may be needed to support operation of a range hood[18, 19] .

4 Discussions

4.1 Practical implications

We observed that a range hood can quickly reduce the kitchen formaldehyde concentration in a kitchen by more than 60% in 10 minutes and avoid dispersion to adjacent living room when kitchen door is closed and kitchen window is open. But the effect is much less significant when kitchen door is open.

4.2 Potential measures to reduce air pollution in kitchens

Air pollutants arising from cooking often violate regulation concentration limits and impose severe health threat against residents. Range hood is one of the main focus in the research community. In addition to window/door status, studies have been conducted to investigate effects of range hood shape [20], guide panels [21], and modulating space locations [22]. Proper operation control such as a coordinated mode of cooktop-range hood-window might be useful improve performance of a range hood. Meanwhile, air curtain technology was also developed to mitigate exposure to air pollutants in a kitchen [23], as well as infection risk in a hospital [24].

China claims to reach carbon neutrality in 2060. Building sector plays a key role as a considerable carbon emitter by combustion of fossil fuels including natural gas.

4.3 Limitations and future study

Formaldehyde monitoring remains challenging due to that performance of sensors is not satisfied. An alternative option is that automatic samplings are conducted continuously, say every hour, and analysis is performed offline.

5 Conclusions

In a short term, many works should be done regarding emission reduction and exposure alleviation. These include improvement of cooktop burner design, development of linked range hood-door-window system, and others. In a long term, strategies developed for carbon neutrality could also play a key role in removing natural gas-related formaldehyde and other pollutants and produce joint health benefits. For example, replacement of natural gas with its hydrogen blend, and ultimately electricity-driven cook facilities, would partially and completely eliminate fuel-related air pollution, respectively.

Acknowledgement
This work was supported by National Natural Science Foundation of China (No. 52178068).

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