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Characterization of volatile organic compounds from different cooking emissions

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HIGHLIGHTS

- The VOCs concentrations emitted from cooking fume were 257.5–3494 μg/m^3.
- The VOCs emission amounts and emission factors were also estimated.
- The sensitivity species of cooking fume were alkanes and alkenes.
- The degree of stench pollution from cooking fume was lighter.

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ABSTRACT

Cooking fume is regarded as one of the main sources of urban atmospheric volatile organic compounds (VOCs) and its chemical characteristics would be different among various cooking styles. In this study, VOCs emitted from four different Chinese cooking styles were collected. VOCs concentrations and emission characteristics were analyzed. The results demonstrated that Barbecue gave the highest VOCs concentrations (3494 ± 1042 μg/m^3), followed by Hunan cuisine (494.3 ± 288.8 μg/m^3), Home cooking (487.2 ± 139.5 μg/m^3), and Shandong cuisine (257.5 ± 98.0 μg/m^3). The volume of air drawn through the collection hood over the stove would have a large impact on VOCs concentration in the exhaust. Therefore, VOCs emission rates (ER) and emission factors (EF) were also estimated. Home cooking had the highest ER levels (12.2 kg/a) and Barbecue had the highest EF levels (0.041 g/kg). The abundance of alkanes was higher in Home cooking, Shandong cuisine and Hunan cuisine with the value of 59.4%–63.8%, while Barbecue was mainly composed of alkanes (34.7%) and alkenes (39.9%). The sensitivity species of Home cooking and Hunan cuisine were alkanes, and that of Shandong cuisine and Barbecue were alkenes. The degree of stench pollution from cooking fume was lighter.

1. Introduction

The content of gaseous pollutant rises considerably in the atmospheric environment as a consequence of the rapid economic development and increases in consumption levels (Lee et al., 2006). It has long been known that cooking fume is regarded as one of the main sources of the urban atmospheric volatile organic compounds (VOCs) in China (Mugica et al., 2001). The number of catering enterprises with annual revenue exceeding 2 million RMB was 23,390 in 2012 according to the National Bureau of Statistics of China, and annual turnover had reached 442 billion RMB, which was 1.7 times higher than that of 2008. The cooking style of Chinese restaurants was dominated by deep-frying, grilling, frying and stir-frying, which was easier to produce a large number of lampblack compared to a single way of cooking in Western (Zhang and Ma, 2011). Cooking fume is generated by edible oil and food after a series of complex chemical reaction at a high temperature, which is a mixture of gaseous, liquid and solid. The detected VOCs chemical constituents emitted from cooking fume could be up to hundreds, which can be divided into alkanes, alkenes and aromatics. The domestic have not made standard for VOCs emission from cooking fume for a long time, which threats to the ecological system

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(Tsigaridis and Kanakidou, 2007) and resident health (Zhang et al., 2008; Pachauri et al., 2013) seriously. VOCs emitted from cooking fume could react with NOx in the air under strong light. That could form photochemical smog, leading to the secondary pollution (Kansal, 2009). The concentration and reactivity of VOCs could also make significant impact on the surface layer of atmospheric ozone (O_3) (Hou et al., 2015; Samarita et al., 2015; Suthawaree et al., 2012). Additional, VOCs contains a variety of cancerogenic substances (Louie et al., 2013), which leads to a series of negative impacts on human health.

To the best of our knowledge, studies about VOCs had mainly focused on fuel combustion (Fernandez-Martinez et al., 2001; Ozil et al., 2009), fugitive emission (Pansegrau et al., 2014; Rao et al., 2005), and transportation sources (Ho et al., 2013; Yao et al., 2007) at home and abroad. However, few investigations had been reported on VOCs emission characteristics of cooking activities. The studies mainly focused on the emission rates of organic compounds currently. For instance, Schauer et al. (2002) conducted an intensive measurement to obtain the emission rates of gas-phase, semi-volatile, and particle-phase organic compounds (e.g., C_1 to C_{27}) emitted from institutional scale food cooking operations. Fullana et al. (2004) measured the emissions of six alkanals, seven 2-alkenals, and 3-alkadienals from heating canola oil and olive oil and draw a conclusion that the emission rates of these aldehydes depended on the heating temperature. The cooking emissions of VOCs was also reported. Wang et al. (2011) investigated the compositions of VOCs from cooking in the Northeast Area of China. VOCs mass concentration and emission amount from cooking emissions were 3407.06 ± 889.5 $\mu g/m^3$ and 994.5 t, respectively. VOCs samples were also collected by Huang et al. (2011) in two residential kitchens where towngas and liquefied petroleum gas were used as cooking fuels. Alkenes and alkanes accounted for 53% and 95% of the total measured VOCs emitted from towngas and liquefied petroleum gas, respectively during cooking periods. Additional, the collection methods of VOCs samples emitted from cooking at present were mainly conducted in the kitchen or in the flue gases directly. However, researches about stationary source emissions showed that part of VOCs could convert into new particles by homogeneous or heterogeneous reaction when high temperature flue gas emitted into atmosphere (Li et al., 2011; Wang et al., 2015). Therefore, acquisition VOCs samplings in high temperature flue gas would overestimate the pollutants emission, which could not represent the real emission characteristics of cooking fume. Given the negative effects of VOCs emitted from cooking on human health and the environment atmosphere as well as the limitations of sampling method, it had become an intractable issue for collecting VOCs samplings accurately and controlling the cooking fume emissions more effectively. In order to obtain VOCs emission characteristics of cooking fume under real conditions, VOCs samples emitted from different cooking styles, including Home cooking, Shandong cuisine, Hunan cuisine, and Barbecue, were collected by a dilution sampling system. The objectives of this study mainly include: (1) analyzing the VOCs emission characteristics, emission factors (EF), and emission rates (ER) emitted from different cooking styles in real situation; (2) investigating the ozone formation potential (OFP) and stench index of VOCs. The research results could provide scientific basis for source apportionment of VOCs and regional air pollution control scientifically.

2. Material and methods

2.1. Sample collection

The accuracy and typicality of VOCs chemical profiles is of great importance when receptor models were applied to source apportionment of VOCs (Liu et al., 2008a, 2008b). However, the traditional sampling methods did not consider the transformation of gaseous pollutants to secondary fine particles when exhaust cooled and diluted with ambient atmosphere. That might lead to high uncertainty of VOCs emission due to the high temperature of flue gas (Li et al., 2011). The flue gas temperature should be 42 °C or lower according to dilution sampling standard proposed by International Organization for Standardization (ISO 25597:2013). However, the fume temperature was above 42 °C at the vent of cooking exhausts measured in this study. Therefore, a dilution sampling system was employed to collect VOCs from cooking fumes under real conditions (Fig. 1).

This system mainly included the following sections: (1) Opium pipe was designed by a combination of Pitot tube and temperature sensor. It was used to drainage the flue gas from cooking fume, measure the instantaneous flow rate and temperature from flue gas. (2) Heating inlet line was used to prevent the temperature bring down when cooking fume go through the opium pipe into the mixing chamber. (3) Zero gas generator was used to provide pure air to mix with cooking fume in the mixing chamber. (4) Mixing chamber was placed in the mainframe box, and the flue gas was diluted to create a drop in temperature to 42 °C below. Relative humidity was also below 70% RH to simulate the physical chemical process. (5) The cooking fume entered the opium pipe, then the mixing chamber through heating inlet line, and mixing diluted fully with diluent gas from zero gas generator.

The dilution sampling system was required a good air tightness to ensure the cooking fume and clean air without being polluted by external ambient air during the mixing process. It is necessary to measure the inlet flow rate and outlet flow rate of the dilution system before the instrument was used and ensure their difference within 5%. In this experiment, the sampling air flow rate and dilution air flow rate could be controlled by mass flow controllers placed in the mixing chamber and zero gas generator in Fig. 1. VOCs samples were collected from closed stainless steel tank through external pump. Finally, the mixed flue gas entered into the tedlar bags under negative pressure condition. That could prevent direct contact between lampblack and the sampling pump, avoiding the pollution of air pump. The flow rate, sampling volume, and dilution ratio could be displayed on screen, and the sampling time could also be set through the touch screen. Parameters could be exported by using a micro SD connected to the instrument.

The sampling point was located on vertical section of the

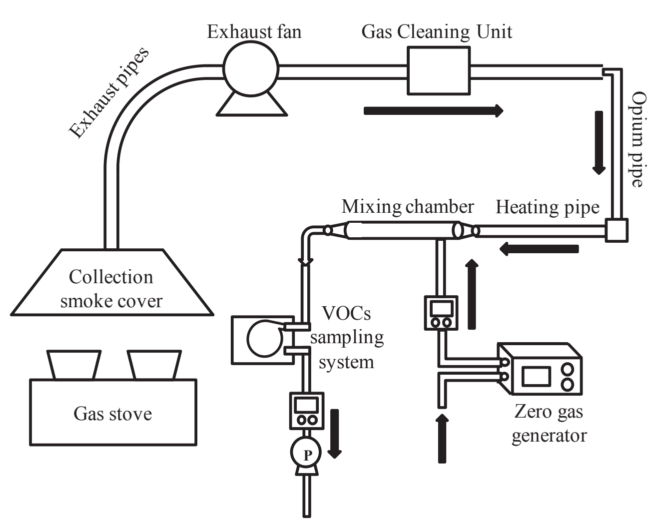

Fig. 1. Structure of dilution sampling system of cooking.