A comprehensive study of volatile organic compounds from the actual emission of Chinese cooking

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Received: 24 December 2020 / Accepted: 6 April 2021 / Published online: 15 March 2022
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Abstract
China’s current perspective for big cities was filled with great population, great number of restaurants, growing gaseous pollutants, and great pollution. Volatile organic compounds (VOCs) were the main components of catering industry gaseous pollutants. In this study, we collected and analyzed VOCs from home cooking (HC), Sichuan and Hunan cuisine (S&H), Shandong cuisine (SD), Anhui cuisine (AH), Beijing cuisine (BJ), and barbecue (BBQ). The result showed that BBQ gave the highest VOC concentration (6287.61 μg m⁻³), followed by HC (1806.11 ± 2401.85 μg m⁻³), SD (2238.55 ± 2413.53 μg m⁻³), AH (1745.89 μg m⁻³), S&H (1373.58 ± 1457.45 μg m⁻³), and BJ (288.81 μg m⁻³). The abundance of alkane was higher among BBQ, Anhui cuisine, and HC with the proportion from 33 to 71%. SD contained higher halohydrocarbons proportion (33%). BJ was characterized by high-oxygenated volatile organic compounds proportion (50%). The ozone formation potential (OFP) of BBQ was much greater than other cuisines. The degree of stench pollution from cooking VOCs of HC was 17.51 ± 16.95, followed by S&H (15.77 ± 16.85), SD (15.12 ± 14.17), AH (16.29), BBQ (2.58), and BJ (1.81). Benzene had the highest life cancer risk (LCR) in SD (2.11×10⁻⁵ ± 3.12×10⁻⁵), following HC (4.50×10⁻⁶ ± 3.83×10⁻⁶) and S&H (4.08×10⁻⁶ ± 4.49×10⁻⁶). Acrolein had a high hazard index (HI) in HC (789.81 ± 768.77), following AH (728.78), S&H (689.89 ± 776.07), SD (664.29 ± 648.77), BBQ (65.93), and BJ (62.84).

Keywords Volatile organic compounds · Cooking cuisines · Ozone formation potential · Stench pollution · Health risk assessment

Introduction
Due to rapid economic development, consumers spend more money in catering industry, especially who live in megacity. According to the data from the National Bureau of Statistic of China, up to December 2019, the total value of retail sales of restaurants in China was 4.7 trillion RMB. Behind the blooming of catering industry, gaseous pollutants were increasing considerably (Barletta et al. 2008; Jiamin et al. 2015; Chiungyu et al. 2017; Lina et al. 2017). Researches showed that catering emission took great affection to the resident environment. Catering emission mainly consisted of oil smoke, particular matter (Lingyan et al. 2004; Lina et al. 2018) and volatile organic compounds (Chen et al. 2018; Shaoqing 2017). VOCs could generate secondary particulate via complex chemical reactions and the reaction products could suspension in the air for a long time (Dall’Osto et al. 2015). VOCs threaten atmosphere environment and resident health (Wang et al. 2018; Kabir et al. 2011; Lina et al. 2018). Some VOCs showed great ozone formation potential (OFP) (Carter 2010; Shuiyuan et al. 2016; Zhiyuan et al. 2017; Hongli et al. 2018). Additionally, the stench of VOCs had a negative effect on the ambient environment (Lina et al. 2017; Kabir et al. 2011; Xufeng et al. 2019; Xiuyan et al. 2012; Yoshio 2003).
Studies of catering industry VOCs mainly focused on the total average concentration and characteristics of components. Wang et al. (2018) analyzed 99 VOCs from C1 to C7; obtained the emission factors based on per person, per kitchen stove, and per hour; established VOC emission inventories based on restaurant scale cuisine types (4124.33–7818.04 t year−1) and restaurant scales (1355.11–2402.21 t year−1); and gave the conclusion that medium-scaled restaurants should be regarded as the most important with respect to regulation of VOCs. The research results provided a methodology for the determination of emission factors and the establishment of emission inventories and aroused managers to pay more attention to catering emissions. Yi et al. (2019) found that the benzene series emissions for three edible oils were high and give a conclusion that the total VOC emission of catering industry could be a function of edible oil consumption. However, the study focused on the emissions of edible oils; the real emissions of cooking process were neglected. Cheng et al. (2016) measured 51 VOCs including 26 alkanes, 9 alkenes, and 16 aromatics and compared the characteristics among home cooking, Shandong cuisine, Hunan cuisine, and barbecue and compared the ozone formation potential (OFP) and stench index. In Cheng et al.’s (2016) research, coefficient of divergence method was used to analyze the level of VOC similarity, and great difference was found between chemical profiles of different cuisine types. Hongli et al. (2018) compared the characteristics among authentic Shanghai cuisine, Cantonese cuisine, fired food, street barbecue, Sichuan & Hunan cuisine, Western fast food, Shaoxing cuisine, canteen, and home cooking in Shanghai and alerted that street barbecue had potential health hazard with high concentration of acetaldehyde. Min et al. (2017) gave the conclusion that C1 to C3 VOCs, whose main components were acetaldehyde, formaldehyde, and acrolein, took 72.27% of VOC emission of traditional Beijing roast duck. To obtain the real emission character of Beijing roast duck, the sampling site which Min et al. (2017) chose was before the purification device. Zhiyuan et al. (2017) measured carbonyl compound emission intensity for different cooking styles and found barbecue > frying > teppanyaki > stir-frying, and for food materials, they found meat dishes > non-meat dishes. Chunyang et al. (2011) analyzed the characterization of VOCs emitted from 5 restaurants and found that the proportion of alkanes, alkenes, and aromatics was similar and the proportion of haloalkanes and haloalkenes has a great difference. However, the sampling sites in their research (Zhiyuan et al. 2017; Chunyang et al. 2011) were after the purification devices, which may not reflect the real emission characterization of VOCs cooking emission.

VOCs were one of the main sources of ozone, especially aromatics and alkene (Carter 1994, 2010). Yafei et al. (2020) measured 99 VOCs in Beijing during ozone pollution days and found that the combustion source generated most VOCs. Vehicle exhaust contributed the most (34.52%) of the total OFP in Shenyang (Zhuobiao et al. 2019). For commercial cooking, Quisheng et al. (2015) found that the average maximum reactivity coefficient (MIR) of Chinese restaurant (3.34 g O3 g VOCs−1) and barbecue (2.93 g O3 g VOCs−1) was at the medium level among different emission sources. Shuiyuan et al. (2016) calculate that the average MIR of Shandong cuisine, Hunan cuisine, and Barbecue were 4.01, 4.31, 4.05 and 4.81 g O3 g VOCs−1, respectively. The average MIR did not show great difference between cuisine types.

The VOCs emitted from catering industry had considerable stench (Buonanno et al. 2009); few studies concentrated on it. According to Cheng (Shuiyuan et al. 2016), only propyl benzene and 1,4-diethylbenzene emitted from barbecue had a certain degree of stench pollution. Kabir’s (Kabir et al. 2011) conclusion strongly suggested that the odor emission depended on the gradients and cooking process.

To have a more comprehensive knowledge of the catering industry, VOC components, and its affect to ambient air quality, 27 restaurants in Beijing were selected and classified as home cooking (HC), Sichuan and Hunan cuisine (S&H), SD, Anhui cuisine (AH), Beijing cuisine (BJ), and BBQ. A total of 101 VOCs from C1 to C12 were detected by gas chromatography-mass spectrometry. The objection of this study mainly include the following: (1) analyzing the VOC emission characteristics from different cooking styles, (2) calculating the OFP of different cooking styles, (3) investigating the stench of index of VOCs.

Materials and method

On-site sampling collection

From May 1st to May 10th in 2019, 27 VOC samples from 27 restaurants, which include 6 cuisine types, were collected during the peak cooking periods(10:30–13:00 and 17:00–20:00) of the restaurants in Beijing. The cuisine types included S&H (8 restaurants), HC (12 restaurants), SD (4 restaurants), AH (1 restaurant), BBQ (1 restaurant), and BJ (1 restaurant).

The emissions of VOCs from restaurants exhausted through exhaust pipes. The airflow was unstable near elbows and junctions and that would decrease the accuracy of the data. To obtain a stable airflow, the sampling points and sampling method were selected via determination of practices and sampling method of gaseous pollutants emitted from exhaust gas of stationary source (GB/T 16157-1996).

The sampling system included the following sections: (1) Sampling pipe was a section of Pitot tube, which was linked to the sampling point. (2) Fume filter could remove the oil fume and particulate matter in the sample gas. (3) Vacuum
box (Restek) was used to transport the emissions into the Tedlar bag (10L). (4) Aerometer was used to measure the air flowrate of the exhaust gas and transfer the results under standard temperature and pressure.

Samples were collected, with a stable 0.5 L min\(^{-1}\) flow rate and persisting 30 min, right before the purification device during the peak cooking periods.

### Sample analysis

The VOCs of cooking oil were first analyzed by gas chromatography-mass spectrometry (GC-MS) in 1995 (Overton et al. 1995). The invention of purge and trap decreased the method detection limit (MDL) of the target VOC. In this study, 101 VOCs containing alkanes, alkenes, oxygenated volatile organic compounds (OVOCs), carbon disulfide, aromatics, and halohydrocarbons were analyzed by GC-MS. The collected samples were pumped into the pre-concentrator which includes 3 modules. Module 1 was set to remove H\(_2\)O and CO\(_2\) and O\(_2\) at −150 °C by liquid nitrogen, and the samples were recovered by desorbing at 10 °C to remove most of the liquid H\(_2\)O. Samples were cooled to −30°C in module 2 to enrich the concentration of VOCs, and then, the samples were heated to 50 °C to release the VOCs into module 3. Samples were cooled to −150°C by liquid nitrogen in module 3 and reheat to 80 °C to make the VOC samples vaporized rapidly. Then, the concentrated VOC samples were carried into GC-MS. A DB-624 column (60 m × 250 μm × 1.4 μm) was used in GC. The column was set at an oven temperature of 35°C for 5 min, then raised to 160 °C at a rate of 5 °C min\(^{-1}\), and finally raised to 220 °C at a rate of 20 °C min\(^{-1}\).

Tedlar bags were pre-cleaned and vacuumed by nitrogen (N\(_2\), 99.99%) to remove any organic compounds before sampling. The Pitot tube was purged with the target gas before the sampling procedure. TO-15 (65 components, 1 ppm, Linde), PAMs (57 components, 1 ppm, Linde), and internal standard gas (4 components, 1 ppm, Linde) were used to generated the calibration curve. The detailed information of 101 VOCs is listed in Table 1. The calibration curves for 101 target VOCs were performed under different concentrations, and the correlation coefficients were all above 0.99. The MDL of 101 species were all ranged from 0.07 to 0.63 μg m\(^{-3}\). The concentration of 101 VOC species was obtained from the calibration curves.

### Data calculation

#### Normalized concentration calculation

The concentrations of 101 VOCs were normalized by Eq. (1).

\[
C_{\text{std}} = C_{\text{test}} \times \frac{Q_{\text{test}}}{nQ_{\text{std}}} 
\]

where \(C_{\text{std}}\) and \(C_{\text{test}}\) represent the normalized and the test VOC concentration (μg m\(^{-3}\)). \(n\) represents the number of the normalized stoves. \(Q_{\text{test}}\) represents the result of aerometer (m\(^3\) h\(^{-1}\)), and \(Q_{\text{std}}\) was equal to 2000 m\(^3\) h\(^{-1}\).

### Ozone formation potential calculation

Ozone formation was related to VOC emission (Hairong et al. 2010). Previous studies mainly focused on other sources, such as gasoline-related emissions, petrochemicals, and liquefied petroleum gas (Yu et al. 2007; Rongrong and Shaodong 2017; Qiusheng et al. 2019; Gang et al. 2015; Jeeranut et al. 2012). In this study, 101 VOC species were detected. Previous studies calculated the ozone formation potential (OFP) for different cuisine types (Hongli et al. 2018; Shuiyuan et al. 2016). The contribution of individual VOC to OFP was evaluated by the MIR which was first claimed by Carter (Carter 1994, 2010). The MIR calculation was based on the following equation:

\[
\text{OFP}_i = \text{VOCs}_i \times \text{MIR}_i
\]

where OFP\(_i\) was defined as the ozone formation potential for individual VOC\(_i\). MIR\(_i\) was the maximum reactivity coefficient of compound \(i\), and the detailed data of MIR was based on Carter’s research (Carter 2010).

#### Stench calculation

The odor of catering VOCs affected the ambient air quality and threatened the resident’s health (Kabir et al. 2011). Shuiyuan et al. (2016) evaluated the stench index by the following equation:

\[
M_i = \frac{C_i}{\mu_i}
\]

where \(M_i\) represented the diluted multiples of component \(i\); \(C_i\) and \(\mu_i\) represented the mass concentration (μg m\(^{-3}\)) and odor thresholds (μg m\(^{-3}\)) of component \(i\) (Yoshio 2003), respectively.

### Health risk assessment

Health risk assessment of cooking VOCs mainly focused on indoor pollutants (Chunyan et al. 2017). There was still lack of reports on health risk assessment about cooking VOCs in emission gas. In our research, we assumed that the emitted gas was directly inhaled by the residents. The exposure concentrations (EC) were estimated following inhalation assessment via Eq. (4) (China. 2019; USEPA. 1992).
| Serial | Compound                  | CAS      | MIR* | Serial | Compound                  | CAS      | MIR* |
|--------|---------------------------|----------|------|--------|---------------------------|----------|------|
| 1      | Propane                   | 74-98-6  | 0.49 | 52     | Methyl isobutyl ketone    | 43209-75-2 | 3.88 |
| 2      | Iso-butane                | 75-28-5  | 1.23 | 53     | Tetrahydrofuran           | 109-99-9 | 2.62 |
| 3      | n-butane                  | 106-97-8 | 1.15 | 54     | Diethyl ether             | 123-91-1 | 2.62 |
| 4      | n-pentane                 | 78-78-4  | 0.37 | 55     | 2-butanol                 | 591-78-6 | 3.14 |
| 5      | n-hexane                  | 110-54-3 | 1.24 | 62     | 3-methylpentene           | 103-65-1 | 2.03 |
| 6      | 2,4-dimethylpentane       | 108-08-7 | --   | 63     | 4-ethyltoluene            | 620-14-4 | 7.39 |
| 7      | Cyclohexane               | 110-82-7 | 1.25 | 66     | 3,4,5-trimethylbenzene    | 108-67-8 | 11.76|
| 8      | 2,3-dimethylpentane       | 565-59-3 | 1.34 | 67     | 1,4-dichlorobenzene       | 106-46-7 | --   |
| 9      | 3-methylhexane            | 589-34-4 | 1.61 | 68     | 2,3,3-trimethylbenzene    | 526-73-8 | 11.97|
| 10     | n-heptane                 | 142-82-5 | 1.07 | 70     | 1,4-dichlorobenzene       | 105-05-5 | 4.43 |
| 11     | Methylcyclohexane         | 108-87-2 | 1.70 | 71     | Naphthalene               | 91-20-3  | 3.30 |
| 12     | 2,3,4-trimethylpentane    | 565-75-3 | --   | 72     | Dichlorodifluoromethane   | 75-71-8  | --   |
| 13     | 2-methylheptane           | 592-27-8 | 1.07 | 73     | Dichlorotetrafluoromethane| 1320-37-2 | --   |
| 14     | 3-methylheptane           | 589-81-1 | 1.24 | 74     | Chloromethane             | 74-87-3  | --   |
| 15     | Octane                    | 111-65-9 | 0.90 | 75     | Methyl bromide            | 74-83-9  | --   |
| 16     | 1,2-dibromoethane         | 4371-77-1 | --   | 76     | Chloroethane              | 75-00-3  | --   |
| 17     | Nonane                    | 111-84-2 | 0.78 | 78     | Trichlorofluoromethane    | 75-69-4  | --   |
| 18     | Decane                    | 124-18-5 | 0.68 | 79     | Dichloromethane           | 75-09-2  | --   |
| 19     | Undecane                  | 1120-21-4 | 0.61 | 80     | 1,1-dichloroethane        | 75-34-3  | --   |
| 20     | Dodecanes                 | 112-40-3 | 0.55 | 81     | Trichloromethane          | 8013-54-5 | --   |
| 21     | Propene                   | 115-07-1 | 11.66| 82     | 1,1,1-trichloroethane     | 71-55-6  | --   |
| 22     | 1-butene                  | 106-98-9 | 9.73 | 83     | 1,2-dichloroethane        | 107-06-2 | --   |
| 23     | 1,3-butadiene             | 25339-57-5 | 12.61| 84     | 1,2-dichlorobutadiene     | 75-87-5  | --   |
| 24     | 2-butene                  | 104-01-7 | 16.16| 85     | Bromochloromethane        | 75-27-4  | --   |
| 25     | 1-pentene                 | 25377-72-4 | 7.21 | 87     | 1,2,3-trichloroethane     | 25323-89-1 | --   |
| 26     | Trans-2-pentene           | 109-68-2 | 10.56| 88     | 1,2,2,2-tetrachloroethane | 79-34-5  | --   |
| 27     | Isoprene                  | 78-79-5  | 10.61| 89     | Vinyl chloride            | 93050-82-9 | --   |
| 28     | cis-2-pentene             | 627-20-3 | 10.38| 90     | Vinylidene chloride       | 75-35-4  | --   |
| 29     | 1-hexene                  | 592-41-6 | 5.49 | 91     | (E)-1,2-Dichloroethene    | 156-60-5 | --   |
| 30     | Styrene                   | 100-42-5 | 1.73 | 92     | cis-1,2-dichloroethene    | 156-59-2 | --   |
| 31     | Hexachlorobutadiene       | 87-68-3  | --   | 93     | Trichloroethene           | 79-01-6  | --   |
| 32     | Carbon disulfide          | 75-15-0  | --   | 94     | Trans-1,3-dichloropropene | 10061-02-6 | --   |
| 33     | Acrolein                  | 107-02-8 | 7.45 | 95     | cis-1,3-dichloropropene   | 10061-01-5 | --   |
| 34     | Methyl methacrylate       | 80-62-6  | 15.61| 96     | Tetrachloroethene         | 127-18-4 | --   |
| 35     | Methyl tertiary-butyl ether| 1634-04-4 | 0.73 | 97     | Chlorobenzene             | 108-90-7 | --   |
| 36     | Vinyl acetate             | 108-05-4 | 3.20 | 98     | 1,3-dichlorobenzene       | 541-73-1 | --   |
| 37     | Acetone                   | 68937-52-0 | 0.36 | 99     | Benzyl chloride           | 100-44-7 | --   |
| 38     | Isopropanol               | 67-63-0  | --   | 100    | 1,2-dichlorobenzene       | 95-50-1  | --   |
| 39     | 2-butanone                | 78-93-3  | 1.48 | 101    | 1,2,4-trichlorobenzene    | 120-82-1 | --   |

* MIR represented maximum reactivity coefficient (Carter 2010)
VOC concentration in the exhaust would be impacted largely by the volume of air drawn through the collection hood over the stove, while the emission of cooking fume was intermittent. Honghong et al. (2019) focused on the emission of NMHC and benzene series of three commonly used cooking oils. The results exhibited that the emissions were increased with the rise of heating temperature, especially when the temperature was over 200 °C. But cooking fume was generated by edible oil and food after a series of complex chemical reaction at a high temperature; the emissions of oils does not reflect the actual emissions. The distribution of VOC categories in different cuisines is shown in Fig. 1. (1) Alkanes contributed 71% of VOC emission in BBQ, which was due to charcoal burning (Bilsback et al. 2019) and incomplete combustion of facts derived from meat (Umano et al. 1987). The main alkane compounds of BBQ were propane (605.37 μg m⁻³), iso-butane (1689.77 μg m⁻³), and n-butane (2091.62 μg m⁻³). For HC, S&H, SD, AH, and BJ, the proportion of alkane was similar and in a high level (16–42%). Because the cooking methods of the above cuisines were similar, which mainly stir-fry. The alkanes were coming from fugitive emissions form natural gas and liquid petroleum gas and from the decomposition of cooking oil. (2) Alkenes contributed 28% of VOC emission in BBQ. The main alkane compounds of BBQ were 1-butene (651.93 μg m⁻³) and 2-butene (1059.96 μg m⁻³), which may share the same original sources with iso-butane and n-butane because the structure, molecular weight, and concentrations of these compounds were similar. For HC, S&H, SD, AH, and BJ, the proportion of alkane was similar and in a low level (4–13%). (3) OVOC contributed 50% of VOC emission in BJ, characterized by high acetone proportion (80% of OVOC). The main OVOC compounds of S&H, AH, SD, HC, and BBQ were acrolein, acetone, and ethyl acetate. Acrolein may come from heating cooking oils and fat (Umano et al. 1987). (4) Carbon disulfide ranged from 34.49 to 73.15 μg m⁻³ for HC, S&H, SD, AH, BJ, and BBQ had a low concentration (1.82 μg m⁻³). The results did not have a great affect towards TVOCs. (5) Aromatics contributed 11–14% in S&H, AH, SD, HC, and BJ and took a minimal ratio in BBQ. (6) Halohydrocarbons contributed 33% of VOC emission in SD, which may be the result of the seasoning which contained large amount of sodium chloride that was widely used in SD. Notably, all the research results showed that alkanes are the dominant species. For example, Cheng et al. (2016) obtained 26 alkanes in home cooking, Shandong cuisine, Hunan cuisine, and barbecue with the abundances at 63.8%, 59.4%, 61.3%, and 34.7%, respectively. He et al. (2020) obtained 8 alkanes in Sichuan and Hunan cuisine and family cuisine with the abundances at 31.8% and 47.9%, respectively. Comprehensively, different abundances of VOCs among all the cooking fumes may be attributed to

\[
RfC \times \frac{CA \times ET \times EF \times ED \times IR}{AT}
\]

where CA represented the VOC concentration (μg m⁻³), ET represented exposure time and the value was 4 h day⁻¹ according to Technical specifications for health risk assessment of ambient air pollution (China 2019). EF represented exposure frequency (day year⁻¹), ED represented exposure duration (year), IR represented inhalation rate (m³ h⁻¹), and AT represented average lifetime (h).

Non-cancerous risk was calculated by hazard quotient (HQ). HQ for pollutants was calculated as dividing the EC by the pollutant specific reference concentration (RfC) (USEPA-IRIS 2009; China 2019).

\[
HQ = \frac{EC}{RfC \times 1000 \mu g/mg}
\]

Collective non-cancerous effects due to exposure to several pollutants were known as the hazard index (HI). The acceptable value of HI was 1 (China 2019).

\[
HI = \sum HQ
\]

Lifetime cancer risk (LCR) was calculated by Eq. (7). The acceptable value of LCR was 1.00×10⁻⁶ (China 2019).

\[
LCR = EC \times IUR
\]

where IUR represented the inhalation unit risk which data can be found in USEPA website (USEPA-IRIS 2009).

Result and discussion

VOC characteristics of different cooking cuisines

A total of 101 VOC species were measured including 28 alkanes, 10 alkenes, 12 OVOCs, carbon disulfide, 16 aromatics, and 34 halohydrocarbons. The average concentrations of detected compounds emitted from different cooking styles are demonstrated in Table 1 and Fig. 2. The total VOCs (TVOCs) of S&H, HC, SD, AH, BBQ, and BJ were 1373.58 ± 1457.45, 1806.11 ± 2401.85, 2238.55 ± 2413.53, 1745.89, 6287.61, and 288.81 μg m⁻³, followed by Hunan cuisine, home cooking, etc. (Shuiyuan et al. 2016; He et al. 2020). However, different concentration levels were exhibited for the same cuisine form. The reason may be attributed to non-normalized concentration, different species being tested, and different sampling times.
differences in the ingredients, operating temperatures, and operation modes.

**Ozone formation potential of different cooking cuisines**

In the present, more attention was paid to the contribution of VOCs from industrial sources to ozone generation, such as petrochemical industry, chemical industry, and furniture painting. However, catering industry should be taken more attention in the case of fewer industrial sources in urban area. In this study, 64 VOC species in the 101 detected VOC species were selected to calculate the OFP of each individual VOC. The rank of total OFP value was not similar with the rank of TVOCs. The OFP for different cuisine types is listed in Table 2.

**Table 2** Ozone formation potential of VOCs emitted from different cooking cuisines

| Components     | S&H avg µg m⁻³ | S&H sd µg m⁻³ | HC avg µg m⁻³ | HC sd µg m⁻³ | SD avg µg m⁻³ | SD sd µg m⁻³ | AH* avg µg m⁻³ | AH* sd µg m⁻³ | BBQ* avg µg m⁻³ | BBQ* sd µg m⁻³ | BJ* avg µg m⁻³ | BJ* sd µg m⁻³ |
|----------------|----------------|----------------|---------------|--------------|---------------|--------------|----------------|--------------|----------------|--------------|----------------|--------------|
| Alkanes        | 519.78         | 526.14         | 755.91        | 1181.42      | 1229.18       | 429.99       | 1237.36        | 5012.45      | 78.45          | 114.02       | 148.87         | 140.45       |
| Alkenes        | 1388.56        | 1462.97        | 2631.88       | 4891.91      | 1682.43       | 1242.02      | 1846.80        | 23800.42     | 114.02         | 114.02       | 148.87         | 140.45       |
| OVOCs          | 1212.10        | 1336.85        | 1286.55       | 1314.77      | 1137.79       | 1046.99      | 1238.55        | 98.34        | 164.42         | 164.42       | 148.87         | 140.45       |
| carbon disulfide | 12.19          | 11.31          | 17.59         | 14.99        | 17.52         | 6.72         | 18.29          | 0.45         | 6.12           | 6.12         | 6.12           | 6.12         |
| Aromatics      | 619.15          | 395.58         | 757.56        | 921.69       | 643.20        | 532.59       | 847.10         | 15.53        | 148.87         | 148.87       | 148.87         | 148.87       |
| Total OFP      | 3751.78        | 3732.87        | 5449.48       | 8324.78      | 4710.10       | 3258.30      | 5188.10        | 28927.19     | 511.89         | 511.89       | 511.89         | 511.89       |
| Average-MIR**  | 2.73           | 2.56           | 3.02          | 3.47         | 2.10          | 1.35         | 2.97           | 4.60         | 1.77           | 1.77         | 1.77           | 1.77         |

Notes:
- Alkanes contained: compound 1–11, 13, 15–20, 22–24, and 27–30; alkene contained: compound 31–41.
- OVOCs contained: compound 44–48 and 50–55. Aromatics contained: compound 56–66 and 68–71.
- The sample amount of this cuisine type was 1 and did not have a standard deviation.
- The units of average—MIR was g O₃ g VOCs⁻¹.
results were consistent with a previous study that the sensitivity component of home cooking, Shandong cuisine, and barbecue was mainly contributed by alkenes, and the OFP accounted for 62.8%, 61.9%, and 75.6% of the total OFP, respectively (Cheng et al. 2016). Wang et al. (2018) also revealed that the top contributor to OFP was alkenes for canteen, authentic Shanghai cuisine, Shaoxing cuisine, and Cantonese cuisine. He et al. (2020) proved that in terms of family cuisine and Shandong cuisine, the sensitivity species were alkenes, and the OFP accounted for 51.7% and 56.6%. The main alkenes of BBQ were 1-butene (4205.33 μg m⁻³) and trans-2-butene (11383.20 μg m⁻³). The reason of high butene emission may be the incomplete combustion of carbon and fats (Umano et al. 1987). BBQ showed minimal aromatic OFP due to the low aromatic concentration of itself. The proportions of OFP from aromatics for S&H, HC, SD, AH, and BJ were similar (14~29%). Notably, acrolein took roughly 30% in OVOCs for all cuisine types and exhibited high OFP proportion (53~92%) of OVOC OFP in our study.

Stench index of different cooking cuisines

In our research, the degree of stench pollution from cooking VOCs of HC was 17.51 ± 16.95, followed by S&H (15.77 ± 16.85), SD (15.12 ± 14.17), AH (16.21), BBQ (2.57), and BJ (1.81) (Table 3). Except for OVOCs, the stench index of different cooking cuisines was similar to the conclusion of Shuiyuan et al. (2016) Notably, acrolein took the main part of the odor threshold and exist a certain degree of stench pollution. Considering the dilution effect of the ambient air toward the emitted gas, the VOCs from catering industry may have trivial contribution to the ambient stench pollution. However, the residents who lived nearby restaurants always complained about the stench pollution. We further calculated the stench pollution of ozone which came from OFP and the results showed a high degree of stench pollution. The stench pollution from the OFP of BBQ was 4218.55, following HC (1214.03 ± 686.89), AH (756.60), SD (686.89 ± 475.17), S&H (547.13 ± 544.38), and BJ (74.65). That maybe one of the reasons why the stench pollution from restaurants annoyed the residents.

Health risk assessment

According to Exposure factors handbook of Chinese population (Adults) (Xiuge and Xiaoli 2014), ET, EF, ED, IR, and AT were assumed at 4 h day⁻¹, 365 day year⁻¹, 25 years, 0.65 m³ h⁻¹, 60 years (525600 h) for LCR, and 25 years (219000h) for HI. The detailed data is described in Table 4. The acceptable values of LCR and HI were 1.00×10⁻⁶.
The values of RfC and IUR were from USPEA-IRIS (USEPA 1992). In our research, the highest value of LCR occurred in the benzene, as for SD (2.11×10⁻⁵ ± 3.12×10⁻⁵) > HC (4.50×10⁻⁶ ± 3.83×10⁻⁶) > S&H (4.08×10⁻⁶ ± 4.49×10⁻⁶) > AH (4.13×10⁻⁶). The LCR of tetrachloroethylene emission in SD was 7.57×10⁻⁶ ± 1.50×10⁻⁵. The LCR of dichloromethane and vinyl chloride was acceptable.

Table 3 shows the HI for different cuisine types. Acrolein had great health risk and contributed 99% in HI. The HI of benzene, toluene, dichloromethane, 2-hexanone, and vinyl chloride was acceptable.
Although acrolein was carcinogen, the IUR of acrolein had not been evaluated.

**Conclusion**

Six cuisine types were selected as database. For TVOCs and OFP, the result showed that BBQ had the highest pollution ability in both TVOCs (6287.61 μg m⁻³) and OFP (28927.19 μg m⁻³). HC was in the second position. The TVOC concentration and OFP of S&H, SD, and AH were similar. Obviously, SD was characterized by high halohydrocarbon proportion (33%). BJ had the lowest pollution ability in TVOCs (288.81 μg m⁻³) and OFP (511.89 μg m⁻³). The standard derivations of TVOC emission of each cuisine types were almost all greater than their average concentrations. Although each cuisine types had their own character flavors, these characters had less relative with their TVOC emission. Alkene emission took 24 to 81% of OFP for all cuisine types. The degree of stench pollution from cooking VOCs of HC was 17.51 ± 16.95, followed by AH (16.29), S&H (15.77 ± 16.85), SD (15.12 ± 14.17), BBQ (2.58), and BJ (1.81). The secondary ozone that came from OFP may be the key pollutant that affects the ambient air quality. For health risk assessment, we found that benzene had high LCR and acrolein had high HI. Acrolein took the main part in both odor threshold and health risk assessment. Since acrolein, a typical aldosterone, had high environmental impact capacity, further study will concentrate on aldosterone.

**Data availability** The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

**Authors' contribution** Formal analysis and writing were performed by Chengyi Sun. Investigation was performed by Liyun Zhao. Conceptualization and data curation were performed by Dr. Huahua Bai and Guoao Li. Resources and project administration were performed by Aijun Shi. Visualization was performed by Xue Chen. Funding acquisition was performed by Lei Nie. All authors read and approved the final manuscript.

**Funding** This work was supported by Beijing Key Laboratory of Urban Atmospheric Volatile Organic Compounds Pollution Control and Application (Z181100005418015, Z171100004417029)

**Declarations**

**Ethical approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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