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Hong Kong Polytechnic University

Department of Civil and Structural Engineering

Characterization of Cooking Fumes in Hong Kong

by

Chen Yi

A Thesis submitted in partial fulfillment of the requirementsfor the Degree of Master of Philosophy

In Nov, 2006

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1. **Chen. Y.**, Ho. K. F., Ho. W. K., Lee, S.C., Jian Zhen Yu, Leung, S.H., 2006. "Polycyclic Aromatic Hydrocarbon (PAH) emissions from commercial restaurants in Hong Kong", submitted to *Atmospheric Environment*.

2. **Chen Y.**, Lee, S. C. 2006. Characterization of cooking fume from commercial sources in Hong Kong *Health Building 2006*, Lisbon, Portugal, June 3-8, 2006.

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Characterization of Cooking Fumes in Hong Kong

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Abstract

Cooking is such a common activities in commercial restaurants and residential households for food preparation. Unfortunately, cooking fume emission can be considered as a serious air pollution source in a developed, densely populated city such as Hong Kong owing to its large number of restaurants and residential dwellings located in urban area. As a result, it is important to exam the chemical compositions and characteristics of the particles emitted by cooking activities.

In this study, six commercial restaurants, including two Chinese restaurants, two western restaurants and two fast food restaurants and one common residential dwelling were selected for sampling and analysis. For commercial restaurants, samples were collected through each restaurant's exhaust ducts during peak hours. Over 80 organic compounds were identified and quantified in this study. For

residential dwellings, different Chinese cooking methods were applied in the kitchen to evaluate cooking emissions.

On average, the mass concentrations of $PM_{2.5}$ in western restaurants were much lower than that of in Chinese and Fast food restaurants. As far as the chemical compositions are concerned, the aerosol is predominately organic matter consisting of organic carbon (OC) (over 70%) in all commercial restaurants as expected.

Fatty acids, alkanes, PAHs and steroids were the major organic compounds emitted from all commercial restaurants. Of the quantified organic mass, over 70% was fatty acids. The mass of $PM_{2.5}$, organic species, the distribution of n-alkanes and PAHs indicated the dissimilarities between different styles of restaurants.

The average emission rates of $PM_{2.5}$, total gas phase PAHs, total particle phase PAHs gas and particle phase organic compounds from commercial sources in Hong Kong were calculated to be 2.30×10^5 kg/year, 1.21×10^3 kg/year, 2.16×10^2 kg/year, 1.62×10^3 kg/year and 3.26×10^4 kg/year, respectively. However, Chinese restaurant has the highest percentage of emission, over 80%, because of its largest number.

Traffic has long been recognized as the major contributors to $PM_{2.5}$ and PAHs. It is calculated that $PM_{2.5}$, gas and particle phase PAHs from commercial cooking sources equate 17.9%, 9.2% and 18.3% of emissions from vehicular traffic sources.

This is the first time a commercial and residential cooking emission profiles database has been collected for Hong Kong. Although the database can only provide a general idea with a high degree of uncertainty, it will become a useful tool to understand and plan strategies to improve Hong Kong's air quality.

Chapter 1

Introduction

1. Introduction

1.1 Emission from Commercial Restaurants

Hong Kong is a small city with a total land area of 1,102 km^2 but with over 10,000 restaurants which have been increasing since the year 2000 (http:// www.info.gov.hk). Various kinds of cuisines including Western, Chinese, Japanese, India and Italy are easily found in this metropolis which makes Hong Kong an undoubtedly gourmet paradise. With such a large number of restaurants of varying sizes, the emissions of cooking fumes from restaurants would be inevitable. Residents nearest to restaurants are prone to nuisances attributed from cooking fume emissions owing to the compact living environment in Hong Kong. According to the statistics of the Environmental Protection Department (EPD), the number of complaints against cooking fume or odour emissions from restaurants increased from 378 cases in 1995 and peaked in 2000 at 1,501 before turning down.

Many studies have been conducted to characterize the cooking fumes emitted from different restaurants. Some studies (Schauer et al., 1999; McDonald et al., 2003; Mugica et al., 2001; Dennekamp et al., 2001) have shown that a variety of pollutants are emitted from the cooking process, for example, fine particles, volatile organic compounds, carbonyls, polycyclic aromatic hydrocarbons, alkanes and fatty acids, some of which are carcinogenetic and mutagenic. In addition, a survey conducted in 1999 indicated that frying, charbroiling, deep-frying and roasting were the main cooking processes that generated most emissions from restaurants (Pang and Wong,

2002).

Although cooking fume emission is often overlooked when compared with other sources such as power plants, industrial sources and vehicular sources, it will produce large quantities of oil fumes in a heavily urbanized city such as Hong Kong owing to its large number and variety of restaurants. What's more, Cooking fume emissions also impact climate change. As a result, the potential impacts of cooking fumes have drawn increasing attention in recent years.

While there have been numerous air quality studies done in Hong Kong, full quantitative determination of cooking fumes research has not yet to be carried out. Research done elsewhere, such as in the United States (Hildemann et al., 1989; Kleeman et al., 1999), are limited and what is available is often not applicable to local conditions because the respective cooking and dining cultures are so different. The preparation and cooking of Chinese and other cuisines in Hong Kong have their unique characteristics. In addition, Hong Kong comprises of more than 60% of Chinese style restaurants. There are as yet no contemporary inventories and source apportionment studies done to fill this particular important knowledge gap.

To be able to establish a baseline database of cooking fumes emissions for Hong Kong and develop source profiles for cooking fume emissions for chemical mass balance (CMB) source apportionment that is directly relevant to Hong Kong would be very useful to assist in better air quality management.

1.2 Emissions from residential cooking

Not only commercial cooking produces large quantities of oil fumes, residential cooking could also create serious air pollution problems. Epidemiological studies (Gao et al., 1988, Wu-Williams et al., 1990, Li et al., 1994) had shown an indication that cooking fume may associate with the incidence of lung cancer especially Chinese women who are responsible for preparing food for the whole family. In fact, the incidence of lung cancer in Chinese women is 2.5-fold significantly higher than in men, despite the fact that they have a lower rate of smoking.

Particulate matter (PM) is one of the major air pollutants in urban areas (APEG, 1999). Epidemiological studies have continued to show an association between particulate matter air pollution and morbidity and mortality from respiratory and cardiovascular disease in cities across the world (Pope and Dockery, 1999).

Numerous studies have presented that smoking and cooking are two main indoor sources to elevate the concentrations of indoors particles (Abt et al., 2000, Dennekamp et al., 2001, He et al., 2004, Liao et al., 2006). Cooking is also found to be a significant combustion source which tends to elevate ultrafine and fine particle levels. Thus, it is necessary to characterize the residential cooking fumes.

However, only a few studies (Schauer et al., 1999, McDonald et al., 2003) have characterized the indoor particles generated by a specific cooking style with identical conditions. Moreover, they are typical American cooking styles which are different from Hong Kong and can not be directly applied. In addition, no study has

reported real time particle concentrations during cooking or the difference in particle emission by different Chinese cooking methods.

Hong Kong is a crowded city and the majority of the population lives in high-rise apartment type buildings. The families have a small floor area, ranging from 30 to 100m^2 (Chao et al., 2002). Thus, the particle's concentrations will be relatively higher. As a result, it is of importance to conduct detailed and systematic research for the purpose of effective indoor air pollution control.

1.3 Objectives

The objectives of this project include:

1. Conduct full quantitative determination of the composition of cooking fumes from commercial restaurants in Hong Kong;
2. Establish a baseline database of cooking emissions profile and characteristics that are directly relevant to conditions in Hong Kong;
3. Compare air pollutants' emission from commercial restaurants and vehicles in Hong Kong;
4. Characterization of the particles generated by two different Chinese cooking style, deep frying and stir frying;
5. Estimate the source strengths of fine particles due to cooking and compare with other indoor sources;
6. To provide insight into policy relevant questions that could assist policy-makers in managing air quality in Hong Kong.

Chapter 2

Literature Review

2. Literature Review

Cooking is such a common activities in commercial restaurants and residential households for food preparation. Unfortunately, cooking fume emission can be considered as a serious air pollution source in a developed, densely populated city such as Hong Kong owing to its large number of restaurants and residential dwellings located in urban area.

2.1 Cooking fume emission

2.1.1 Cooking oil fume

Cigarette smoking is considered to be the most important cause of lung cancer, especially in men (IARC, 1985; Loeb et al., 1984). However, it accounts for only a minority of lung cancer cases in Chinese women (MacLennan et al., 1977; Mumford et al., 1987). The incidence of lung cancer in Chinese women is relatively high, although they rarely smoke (Hinds et al., 1981, Law et al., 1976, Koo et al., 1985).

Epidemiologic studies (Gao et al., 1988, Wu-Willliams et al., 1990) showed that indoor air contaminants derived from cooking oils were highly associated with the incidence of lung cancer in Chinese women who usually prepare dinner for the whole family and exposed more to the cooking oil fume.

Stir frying, frying and deep frying are three types of traditional and common Chinese cooking methods involving frying food in oil. Before frying food, Chinese

women have the cooking habit of waiting for the oil to reach a high temperature before beginning to cook (Zhu et al., 2001). Ko et al, (Ko et al., 1997) found that women who have this cooking habit had 2.5-fold significantly higher lung cancer risk.

Many experimental studies have been carried out to investigate the carcinogenicity and mutagenicity of the cooking fume and some of them suggested that there were large amounts of aldehydes from the headspace of cooking oil and food. Yasuhara and Shibamoto (Yasuhara and Shibamoto., 1989) studied the aldehydes and ketones in the headspace of heated pork fat and showed that the major compounds produced were hexanal, heptanal, and pentanal. Yasuhara (Yasuhara et al., 1991) also analyzed the vapors from corn oil, cottonseed oil, and soybean oil and identified 11 aldehydes. Another study conducted by Yasuhara (Yasuhara et al.,1995) found that the largest quantities of aldehydes formed from various kinds of fish flesh during heat treatment were formaldehyde and acetaldehyde. Chung et al. (Chung et al., 1993) identified 22 aldehydes in headspace samples of peanut oil undergoing thermal treatment. Umano et al. (Umano and Shibamoto, 1987A, Umano and Shibamoto, 1987B) identified 18 aldehydes and acrolein from overheated beef fat and heated cooking oil. Wu et al (Wu et al., 1992) reported that there was a significant amount of aldehydes from heated edible oils during storage. Another study (Takeoka et al., 1996) found that there was a high amount of aldehydes in used frying oils. Snyder (Snyder et al., 1985) determined 19 aldehydes from the headspace of soybean oil and sunflower oil stored at 60° C for 8 days. Mussinan and Walradt (Mussinan and Walradt., 1974) isolated 25 aldehydes from the volatile constituents of pressure-cooked pork liver. Recently, a study

conducted in China (Zhu et al.,2002) found that there were large amounts of hexanal and 2-heptenal in the cooking oil fume and that the total aldehyde peak areas of the condensate from four kinds of oil (soybean salad oil, rapeseed oil, rapeseed oil and lard) were around 30-50% of the total peak area at 270-280° C. In addition, Chiang et al (Chiang et al., 1997, Chiang et al., 1999) also found carcinogens, for example, benzo(a)pyrene (BaP), dibenz(a,h) anthracene (DBahA), Benzo(b) fluoranthene (BbFA) and benzo(a)anthracene (BaA) in the extracts of oil fumes.

2.1.2 Emissions from Restaurants

Besides the studies carried out on the cooking oil emissions, recently, some research were conducted on the emission from restaurants which served different dishes cooked by traditional Chinese methods, such as deep-frying and frying, etc.

A study conducted in Shenzhen (He et al., 2004) examined the chemical compositions and characteristics of cooking fumes from Cantonese and Hu nan restaurants. He found that more than half of the $PM_{2.5}$ mass is due to organic compounds, and organic compounds account for 26.1% of bulk organic particle mass and 20.7% of $PM_{2.5}$. Fatty acids, diacids and steroids were the major organic compounds emitted from both styles of cooking. Of the quantified organic mass, over 90% was fatty acids.

Li et al, (Li et al., 2003) focused on PAH emissions from different types of restaurants and found several PAHs in the cooking exhaust. This study also reported

that, for emission rates of total PAHs, a consistent trend was found for the four types of restaurant: Chinese (2038 kg/year) > Western (258 kg/year) > Fast Food (31.4 kg/year) >Japanese (5.11 kg/year). Zhu (2003) reported that the mean concentration of total PAHs in commercial kitchens was 17 μg/m^3, consisting mainly of 3- and 4- ring PAHs, and 7.6 μg/m^3 in domestic kitchens, where 2- and 3-ring PAHs were predominant, especially naphthalene. He also found that boiling produced the least levels of PAHs when compared to frying and broiling. Schauer et al (Schauer et al., 2002) reported that carbonyls and fatty acid (n-alkanoic and n-alkenoic acids) make up a significant portion of the organic compounds emitted from all three seed oil cooking procedures. A comprehensive study was carried out in Singapore to investigate the physical (number and mass concentrations and size distribution) and chemical (metals) properties in a typical Chinese food stall where stir frying in a wok is the most common cooking method using gas stove. It is found that the average mass concentrations of fine particles and metals increased by a factor of 12 and 11 respectively. Another study conducted in Hong Kong revealed that over 40 organic compounds such as glycerides, free fatty acids, aliphatic hydrocarbons, polyaromatic hydrocarbons, polyaromatic amines and carbonyl compounds were identified in the commercial cooking exhaust.

2.1.3 Meat Charbroiling Emission

Charbroiling and grilling are special cooking operations which will generate more pollutants when compared to other cooking methods. As a result, many studies have been focused on the charbroiling and grilling emission.

Rogge (Rogge et al., 1991) found that meat cooking operations is a major source of organic aerosol emissions to the urban atmosphere, comprising up to 21% of the primary fine organic carbon particle emissions in the Los Angeles area. Kleeman (Kleeman et al.,1999) indicated that the smoke from meat charbroiling shows a major peak in the particle mass distribution at 0.1-0.2 μm particle diameter, with some material present at larger particle sizes. Another study (McDonald et al., 2003) reported that $PM_{2.5}$ emission rates varied by type of appliance, meat, meat-fat content, and cooking conditions. The $PM_{2.5}$ rates for charbroiling meats ranged from 4.4 to 11.6 g/kg of uncooked meat. High-fat hamburger cooked on an underfired charbroiler emitted the highest amount of $PM_{2.5}$. One study (Pang and Wong., 2003) carried out in Hong Kong showed that the PM_{10} and $PM_{2.5}$ concentrations reached 84.94 $\mu g/m^3$ and 27.25 $\mu g/m^3$ when frying vermicelli with beef. Deep frying seed generated less particles, the PM_{10} and $PM_{2.5}$ concentrations increased to 11.61 $\mu g/m^3$ and 4.58 $\mu g/m^3$ respectively. The PM emission factors of different studies are shown in the following table.

Table 2-1-1 Comparison of particle emission rates between previous meat-cooking studies

Previous Meat Cooking Studies	**Cooking Style**	**PM Emission Rate (g/kg meat)**
Pang et al., 2003	Frying Vermicelli with beef	15
Hildemann et al., 1991	Charbroiling regular hamburger meat (25% fat)	39.8
Hildemann et al., 1991	Charbroiling extralean meat	7
Hildemann et al., 1991	Frying meat	1
Schauer et al.,1999	Charbroiling hamburger meat (25% fat)	18.8
Norbeck, 1997	Charbroiling hamburger meat (25% fat)	32.7
McDonald et al.,2003	Charbroiling hamburger meat (25% fat)	15.0
Norbeck, 1997	Auto-Charbroil hamburger meat (21% fat)	4.5
McDonald et al.,2003	Auto-Charbroil hamburger meat (21% fat)	7.4
Norbeck, 1997	Charbroiler-Chicken with skin	7.2
McDonald et al.,2003	Charbroiler- Chicken with skin	10.4

In addition, water-soluble K^+ and Cl^-, which are used as indicators of wood smoke in source apportionment studies, were also present in meat-cooking emission (Schauer er al., 1999, Mcdonald et al., 2003). Schauer reported that potassium occupied 34% of fine particle mass while chlorine occupied 16%. Mcdonald found that hamburger cooked on an underfired charbroiler emitted the highest amounts of the elements and ions, yielding 60.1mg/kg water-soluble K^+, 17.0mg/kg $SO4^{2-}$, and 14.2 mg/kg Cl^-.

Hildemann (Hildemann et al., 1991) also found that the fraction of organic carbon in the particle emissions was 58.8% which was not statistically different from the result, 33.8% reported by Schauer (Schauer et al., 1999). However, Mcdonald

(Mcdonald et al.,2003) showed that organic carbon constitute the largest fraction of $PM_{2.5}$ emissions from meat cooking on a charbroiler, accounting for approximately 96% of the fine particle mass. The study conducted in Hong Kong (Pang et al., 2003) stated that organic carbon reached 15086.0 mg/kg when frying vermicelli with beef and 85.15 mg/kg when deep frying seafood. However, the fine particle matter contained virtually no elemental carbon.

In addition, Pang (Pang et al., 2003) also measured the OC/EC concentrations in the cooking exhaust fume from three commercial restaurants. The Western restaurant had the highest OC concentration, 802.02 $\mu g/m^3$ while the Chinese restaurants had highest EC concentrations, 4.75 $\mu g/m^3$.

PAHs were also found in the smoke of meat charbroiling operations. Mcdonald (Mcdonald et al.,2003) found that most PAH was emitted from auto-charbroiling hamburger meat, which reached 49.05 mg/kg meat. However, Pang (Pang et al., 2003) reported that virtually no PAH were found in the cooking fume.

2.2 Indoor particulate matter during cooking

2.2.1 Cooking Process

Freshly cut meat usually contains ~75% water, 15~20% proteins, and ~5-10% fat (Mottram et al., 1982, Offer et al., 1983).

Cooking has a drastic effect on the muscle tissue and fat (Rogge et al., 1991). As soon as meat is heated to between 40 and 50^{o}C, the muscle fibers lose their myosin protein solubility, which indicates protein denaturation and membrane deterioration in the contractile system (Wassermann, 1972). Between 65 and 75 ^{o}C, meat begins to shrink along the muscle fibers due to denaturation of connective tissue proteins and loss of water. The shrinkage for nonshredded meat comprises 25-35% with a loss of water of up to 40% (Offer et al., 1983).

Deep frying and stir frying, the so-called dry cooking methods (in contrast to boiling, steaming and stewing) can heat the meat to temperatures well above the boiling point of water. This produces a much higher thermal stress on the surface of the dry cooked meat.

Compounds are released during meat cooking that area formed by oxidation, decarbonxylation, fragmentation, recombination, rearrangement, condensation, and cyclization reactions of the precursor raw meat components (Frankel, 1982). The uncooked fat component of meat contains large amounts of bound unsaturated and saturated fatty acids. The most common fatty acids are palmitic and stearic acids and their unsaturated homologures. These fatty acids, which have melting points between 12 and 69^{o}C and boiling points up to 360^{o}C, either can leave the frying meat

unaltered in the liquid phase or can be vaporized at the outer surface (Rogge et al., 1991).

2.2.2 Indoor particulate matter

Particulate matter (PM) is one of the major air pollutants in urban areas (APEG, 1999). Many studies have shown that fine particles linked to mortality and morbidity of human beings (Pope and Dockery, 1999; Wallace et al., 2004, He et al., 2005). Most have focused on the mass of particulate matter less than either 10 or 2.5 μm in aerodynamic diameter (PM_{10} and $PM_{2.5}$). It has been hypothesized that these effects may be due to the nm sized particles (ultrafine particles (UFPs)) comprising the largest number of particles, rather than the mass which is principally determined by larger, greater than 1 μm, sized particles (Seaton et al., 1995). This implies that particle numbers could be a better metric than particle mass for predicting health effects and for control purposes. This ultrafine hypothesis was based on animal studies that showed nm sized particles to be toxic, whereas larger particles of the same material were not (Ferin et al., 1990, Ferlin et al., 1992). It was recognized that most studies relating health effects to particulate pollution are based on PM10 measured in urban air, where UFPs generated by combustion is an important component.

Since people spend approximately 90% of their time indoors (Fishbein and Henry, 1991; Jenkins et al., 1992; Byrne, 1998), indoor exposures are major contributors to total personal exposures (Janssen et al., 1998).

Numerous studies have presented the contribution of indoor sources (cooking, cleaning, smoking, etc) to elevate the concentrations of indoors particles (Abt et al., 2000, Dennekamp et al., 2001, He et al., 2004, Liao et al., 2006). Each indoor source results of emission of particles in a specific size range. For instance, combustion tends to elevate ultrafine and fine particle concentrations whereas mechanically generated sources (sweeping, dusting, resuspension from clothes and carpets) tend to elevate concentrations in the coarse fraction. Among these indoor sources, cooking is found to be a significant combustion source, with the vast majority of them in the submicrometer range, containing a host of organic material (Morawska and Zhang, 2002). Several studies have investigated relations between cooking and respiratory symptoms, and some have shown that children who live in houses where gas is used have more respiratory symptoms than children who live in houses where other cooking fuels are used (Melia et al., 1977, Volkmer et al., 1995). Dick et al (2001) also showed an association between gas cooking and proinflammatory effects in lung cells. These effects have generally been attributed to increase in concentrations PM_{10}.

Quantitative assessment of cooking emission characteristics in real situations is a complex task, and therefore only limited studies were found. Dennekamp (2001) measured the peak concentrations of ultrafine particles for diffenent cooking methods, and found frying bacon on the gas rings caused the highest peak concentration of numbers of UFPs, 590000 particles/cm^3. He also reported that immediately after the gas rings were turned on, the highest numbers of particles were in the very fine size range, but thereafter the particles grew in size with time. Wallace et al., 2004

measured the particle counts in a full range of sizes, from 0.01 to 2.5μm, produced during cooking. The selected cooking episodes (mostly frying) were capable of producing about 10^{14} particles over the length of the cooking period, more than 90% of them in the ultrafine (<0.1 μm) range. More than 60% of this volume occurred in 0.1-0.3 μm range. Wallace also found that cooking was capable of producing more than 10 times the ultrafine particle number observed during noncooking periods. Levels of $PM_{2.5}$ were increased during cooking by a factor of 3. Another study conducted in Australia (He et al., 2004) found that frying, grilling, stove use, toasting, cooking pizza, cooking, could elevate the indoor submicrometer particle number concentration levels by more than five times, while $PM_{2.5}$ concentrations could be up to 30 and 90 times higher than the background levels during frying and grilling, respectively. He has also reported the concentrations and emission rates of $PM_{2.5}$ and submicrometer particles for several indoor activities. Cooking results in emission of 0.11 ± 0.99 mg min^{-1} of $PM_{2.5}$ and 5.67 ± 8.61 (particle $min^{-1} x10^{11}$) ultrafine particles. Grilling was found to have the highest emission rate for PM2.5 and ultrafine particles, which reaches 2.78 ± 17.8 mg min^{-1} of $PM_{2.5}$ and 7.34 ± 5.06 (particle $min^{-1} x10^{11}$) particles. Wallace (1996) concluded from a review of three major studies on particle concentrations in US homes, that cooking results in emission of 1.7 ± 0.6mg min^{-1} of $PM_{2.5}$, and sources other than cooking and smoking in emission of about 0.018 ± 0.017 mg min^{-1}.

Abt (2000) has also conducted an intensive study in an effort to characterize sources of indoor particles. Cooking, including broiling/baking, toasting, and

barbecuing contributed primarily to particulate matter with physical diameters between 0.02 and 0.5μm, with volume median diameters of between 0.13 and 0.25 μm. Frying was associated with particles from both $PM_{0.02-0.5}$ and $PM_{0.7-10}$. The volume concentrations of $PM_{0.02-0.5}$ and $PM_{0.7-10}$ reached 28.85 ± 15.33 $(\mu m/cm)^3$ and 19.45 ± 18.44 $(\mu m/cm)^3$ respectively during frying. Liao (2006) reported that cooking had size-integrated source emission rates of 0.042 ± 0.024 particles s^{-1}. Cooking was a significant contributors to indoor particle levels for particle sizes from 0.5 to 5 μm in that the percent contributions to indoor concentrations were 0.334 ± 0.02 particles min^{-1}. Siegmann (1996) have measured the size distribution of the aerosol produced from heating rape seed oil at different temperature. They showed that diameter and concentrations of numbers increased with increasing temperature. The mean droplet diameter ranged between 30 nm at 223° C and 100 nm at 256° C. The concentration of numbers of particles with a diameter less than 100nm rose rapidly with temperature, the oil at 256° C releasing about twice as many particles than the oil at 223° C.

Chapter 3

Methodology

3. Methodology

3.1 Commercial Restaurants

3.1.1 Sampling Site

The commercial restaurants were selected based on the following criteria:

a) Large number of branch restaurants;

b) Cuisine is representative and is typical in Hong Kong; and

c) Likely to generate large amount of pollutants.

In addition to the fulfillment of the selection criteria, the selected restaurants also needed to satisfy certain sampling requirements for cooking emission sampling. Roof top access, electricity supply, sampling space, floor plans, exhaust information and air pollution control equipment were factors also considered for selection of restaurant for sampling.

2 m^2 of space was required for sampling equipment and numerous site visits were conducted where this space was not available in the kitchen for sampling. In addition, safety issues resulting from sampling within the kitchen area were also a concern. Therefore, sampling was not performed in the kitchen area but either at the roof top or inside the plant room where sufficient space and access to exhaust for sampling were available.

All restaurants sampled had an independent exhaust system. This ensured that the cooking fumes sampled were directly generated from the target restaurant only and not from several restaurants which can often occur resulting in exhaust ducts being

combined together.

In this study, two Chinese restaurants (CR1 and CR2), two western restaurants (WR1 and WR2), two fast food restaurants (FR1 and FR2) were selected for sampling. Table 3-1-1 lists the exhaust duct length, duct width, exhaust temperature and humidity, the mean duct outlet velocities, the main cooking methods, served food and types of food oil used for each restaurant.

Table 3-1-1. Background information for all sampled restaurants

	CR1	**CR2**	**WR1**	**WR2**	**FR1**	**FR2**
Duct Length (cm)	125	80	100	56	50	70
Duct Width (cm)	66	60	64	52	48	70
Temperature (°C)	32.62	33.43	27.65	30.35	27.35	32.37
Humidity (%)	63.52	58.22	43.50	56.31	49.88	60.26
Velocity (m/s)	12.17	5.50	3.50	7.44	11.33	4.42
Type of Cooking oil	Vegetable oil Peanut oil	Vegetable oil Peanut oil	Peanut Oil Butter	Peanut Oil Butter	-	-
Served Food	Dim Sum	Dim Sum	Steak	Steak Spaghetti	Hamburger	Hamburger Rice
Cooking Methods	Steaming Stir-frying Frying Deep frying	Steaming Stir-frying Frying Deep frying	Steaming Stew Pan frying Grilled Roast	Steaming Stew Pan frying Grilled Roast	Frying Deep frying	Frying Deep frying

Note: * CR: Chinese Restaurant; WR: Western Restaurant; FR: Fast Food Restaurant

3.1.2 Sampling protocol

Cooking fume samples were collected from the exhausts of the restaurants. The duration of the sampling was correlated to the peak hours of the restaurants. The sampling duration was 1.5 hrs for all restaurants except restaurant CR1. The sampling duration of restaurant CR1 was 2 hours. Because the peak hour in this restaurant is 2 hours.

In a typical sampling, the sampling probe connected to the inlet stilling chamber (Fig.3-1-1) was inserted inside the exhaust duct of the restaurant through a sampling hole. The aerosols were subsequently collected to different sampling medium under suction provided by a sampling pump.

Four samples plus one background sample and one blank sample were collected for each restaurant in order to exam the variability. The background samples were usually collected when no cooking activities were carried out in the kitchen. The sampling time and procedure for background sample is identical to other cooking samples. The background sample was collected to evaluate the ambient air quality.

3.1.3 Sampling Instrumentation

The DRI MEDVOL Gas/Particle sampler consists of a $PM_{2.5}$ cyclone, an inlet stilling chamber, a conical plenum, open faced filter packs, differential pressure flow control and a pump, as shown in Fig. 3-1-1.

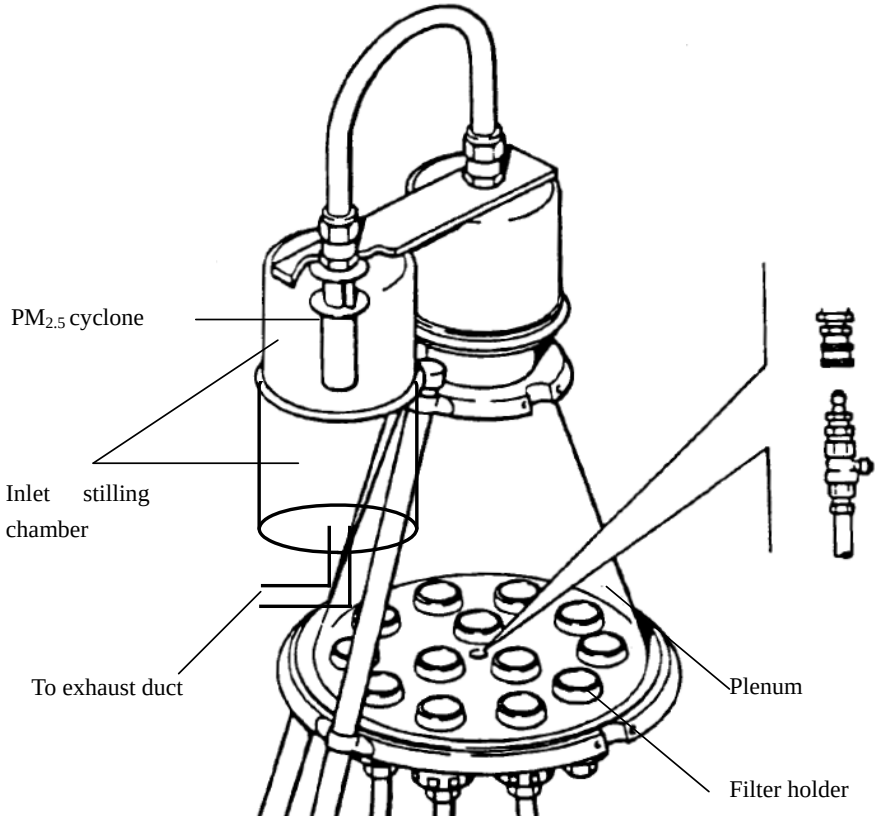


Figure 3-1-1 DRI MEDVOL Gas/Particle sampler

The $PM_{2.5}$ cyclone (Bendix 240) operates at 113 L/min which remove particles larger than 2.5 micrometers in aerodynamic diameter from the air stream. The desired flow was provided by a pump (GAST 1023 ¾ HP carbon-vane vacuum pump) and was controlled by a differential pressure flow valve. The flowrate was continuously monitored and logged by a mass flow meter (TSI, model 4030E). After the air was drawn from the cooking fume exhaust duct, it passed through the cyclone and the air was diffused inside the plenum. The plenum was coated with nitric acid-treated Perfluoro alkoxyalkane (PFA) Teflon. The conical shape of the plenum diffused the

airflow and minimized particle deposition. The plenum base has 13 filter holder ports. The Savillex 47-mm injection-molded PFA Teflon open faced filter holder was used for this project. The filter holder has a tapered extender section which can be mated to the plenum with an O-ring in a retainer ring. A filter backing tray was equipped to reduce flow resistance and to create a homogeneous deposit (Chow et al., 1993).

A 47mm Teflon-membrane and quartz-fiber filter were placed separately in a filter holder. All the filters were weighed before and after sampling in a temperature and humidity controlled environment (20 ± 5°C, 35 ± 5% RH) to determine mass concentrations. The filters were placed inside the PetriSlides prior to and after sampling.

The filters were stored inside an icebox during the transportation from the laboratory to the sampling sites. The sampling flowrate was 22.3 L/min for the Teflon-membrane and quartz-fiber filter and was continuously measured by a mass flow meter (TSI, model 4043E) and recorded by a data logger. All the filters were sent to DRI for mass and chemical species analyses. Teflon filters were used to collect particles for mass and elemental analysis by X-ray Fluorescence (XRF). Quartz filters were used to collect samples for organic and elemental carbon analysis (using TOR and TOT methods) and for water soluble inorganic ions by Ion Chromatography (McDonald, et al., 2003).

Particle and vapor phase PAHs were collected onto a 102mm diameter glass fiber (Tisch Environmental) followed by polyurethane foam plug PUF/XAD-2/PUF. The filter collected particles and was used to determine particle-phase PAHs and other

particle phase organic compounds. The PUF/XAD-2/PUF plug was used to determine vapor phase PAHs and alkanes. Air was drawn through the filter supported by a 16-mesh stainless steel screen and followed by the sorbent cartridge inside a fall column. The air flow was provided by an independent external pump (GAST 1023 ¾ HP carbon-vane vacuum pump). The sampling tube of the fall column was connected to the filter holder attached at the base of the plenum. The flowrate through the filter and the cartridge was fixed at 66 L/min. In addition, the flowrate is monitored by flowmeter (TSI, model 4043E) and data logger.

3.1.4 Chemical Analysis

3.1.4.1 Gravities Analysis

To determine particle mass by gravimetric analysis, all filters were pre- and post-weighted at least twice (weighting is reported if the difference between two weights deviated larger than 10%). The net weight was obtained by subtracting the initial weight from the final average weight. Before weighting, all filters were equilibrated for a minimum of 24 hours at an equilibration temperature of 20-23˚C and relative humidity of 30-40%. The filters were weighted using a Microbalance (Model MC5, Sartorius AG, Goettingen. Germany) with the sensitivity of ±1 μg in 0-250 mg range. The net weights were divided by the total sampling volume.

The Model MC5 Sartourius Microbalance was used to weight filters to the nearest 0.001 milligram. The separation of the weighing cell and evaluation unit ensures

maximum precision – disturbing thermal influences were practically eliminated. The weighting cell and evaluation unit are interfaced together and also interface with a power supply unit. Automatic door functions on the glass draft shield facilitate operation and prevent vibrations. The Model MC5 Sartorius Microbalance contains a fully automatic, temperature-controlled internal calibration and linearization feature, which automatically calibrates the balance when necessary. In operation, a filter was placed on the weighting pan and the door of the glass draft shield was automatically closed. After approximately 20 to 30 seconds, the filter weight was registered on the digital display of the evaluation unit.

3.1.4.2 GC/MS Analysis

The sample analyses were carried out by Hong Kong University of Science and Technology. The determination of gaseous phase PAHs is an HOKLAS accredited method (method code: GL-OR-10) using HPLC-UV-FLD technique. Particle phase PAHs were collected on the 102mm diameter glass fiber (Tisch Environmental). The filters are spiked with 250 μL each of $C_{24}D_{50}$ with the concentration of 25ng/uL, Phe-D10, with the concentration of 5ng/uL, $CD_3(CH_2)_{14}COOH$, with the concentration of 60 ng/uL, Phthalic acid-D4, with the concentration of 25 ng/uL and Levoglucosan-13C, with the concentration of 1540 ng/uL. They are then Soxhlet-extracted with a mixture of ~140 mL high purity dichloromethane and ~140 mL high purity methanol. The extract is reduced in volume to approximately 5 mL using a rotary evaporator and then filtered through glass wool to a test tube and rinsed

with dichloromethane. To the extract 250 μL of high purity acetonitrile is added. [Acetonitrile serves to replace methanol upon further solvent evaporation to 250 μL. Methanol has to be replaced due to its reaction with silylation reagent BSTFA that is to be used for derivatizing –OH and –COOH containing compounds.] The samples are then blown down to 200 μL. The samples are then split into two equal portions of 100 μL and transferred to two Teflon-lid lined vials. One portion is used to analyze PAHs as non-polar species. A spike sample and a spike reference sample are also prepared. The spike sample is treated in the same way as aerosol samples. The spike reference sample does not go through the soxhlet extraction and volume reduction steps. The spike sample and the spike reference sample are used to assess recovery for each batch of samples. Then they are ready to inject for GC/MS analysis (Appendix 1 and appendix 2)

3.1.5 Quality Assurance and Quality Control

3.1.5.1 Overall QA/QC Procedure

A field blank sample was taken at every site in this study. The field blank is a sampling follow all handling procedures except actual sampling, For example, Quartz and Teflon filters were transported from the laboratory to the site and placed inside the Savillex holder without actual sampling (switching on the pump). The sampling time and procedure for field blank is identical to other cooking samples.

3.1.5.2 QA/QC for Sampling Instrumentation

Prior to the sampling, a leak test is performed for the plenum. This is to ensure that the plenum was assembled adequately without leakage. Flowrates from the exhaust tubing and after the plenum were monitored simultaneously by an online mass flow meter (TSI, model 4030E). The minimum flowrate difference achieved in the laboratory was smaller than 1%. The 1% difference in flowrate is probably due to the workmanship of the plenum and could not be further reduced. Thus, this criterion was applied to check the plenum on-site after transportation and assemble. All the sampling was conducted with under this criterion. After sampling, all the parts of the sampling unit including inlet stilling chamber, cyclone, plenum and the tubing was cleaned with detergent, deionized distillated water, methanol and n-hexane (Rogge et al., 1991). The quartz filters were baked for several hours inside a furnace at 900°C to reduce their carbon blank.

Similar to the plenum, a leak test was performed for the fall column after being transported and assembled on-site. The flowrates prior and after the fall column were checked simultaneously by an online mass flow meter (TSI, model 4030E). No flowrate difference was observed during the assembling of the fall column in the laboratory. Therefore, the fall column was assembled until no flowrate difference was observed on-site.

For the PUF samplers, the cartridge was wrapped with baked (550°C) aluminum foil before and immediately after sampling. The cartridge was stored inside the icebox at -4°C except the sampling period. Prior to the sampling, the quartz filter was baked

at 550°C for 2 hours to remove any possible PAHs adsorbed in the filter. The flowrate throughout the sampling was monitored by an online mass flow meter (TSI, model 4000) and recorded by a data logger. If a 10% difference between the initial and final flowrate is observed, the sample will be considered invalid as (USEPA, 1999a).

3.2 Residential Dwellings

3.2.1 Sampling Site

A residential dwelling located in the rural area of Hong Kong was chosen as the sampling site. Liquefied petroleum gas (LPG) was used as cooking fuel. The volume of the kitchen was measured to be 5.704 m^3. No fume extractor was installed in this kitchen in order to guarantee the cooking fume samples collected not affected or dispersed by others except natural air exchange

All the windows and doors were open during experiment in order to simulate a real cooking situation. Exhaust fan was installed and in operation when cooking was taking place in the kitchen. No cooking was conducted except sampling time.

3.2.2 Sampling Protocol

Two cooking practices were simulated to investigate the particle emission from home cooking. One is deep frying pork chop and the other is stir frying pork chop which are two popular cooking methods in Hong Kong.

All the ingredients used for the dwelling cooking were purchased in a local supermarket. The condiments used were of the same category and of the same brand. The weight of each ingredient used was controlled and quantified each time for consistency. For fluid ingredients volumes, for example, oil, was measured using a measuring cup. Detailed information is listed in Tables 3-2-1.

Table 3-2-1 Cooking ingredients of deep frying pork chop and stir frying pork chop

Ingredient	**Amount**	**Ingredient**	**Amount**
Deep Frying Pork Chop		**Stir Frying Pork Chop**	
Pork Chop	400 g ±10 g	Pork Chop	400 g ±10 g
Salt	3.33 g	Salt	3.33 g
Sugar	5.33 g	Sugar	5.33 g
Cooking Oil (Canola Oil)	200 ml	Cooking Oil (Canola Oil)	50 ml
Corn Starch	16.68 g		
Egg	2		
Bread Crumbs	124.05± 24.81g		

In addition, an electronic thermograph was used to measure the oil temperature prior the pork chops being poured into the wok. The average oil temperature measured in this study is 164.0±2.9ºC.

A total of twenty one cooking test were carried out in this study. Nine cooking episodes involved deep frying pork chops in 200ml canola oil. Firstly, salt, sugar and corn starch were speared on all pork chops. Afterward, put the salted pork chop into the mixed yolk and egg white, then finally sprayed fixed amount of bread crumbs onto their surfaces. Then turn on the stove, when the oil reached around 160 ºC, poured in one piece of pork chop. It takes 2.5 minutes to deep fry one side of the pork chop, and

another 2.5 minutes to deep fry the other side. The experiment duration was 30 minutes and a total of six pieces of chops were consumed. Another type of cooking included here is stir-frying. For this type of cooking, pork chops were stirred in 50ml canola oil. Only salt and sugar were speared on the pork chops and the cooking procedures were exactly the same.

The backgrounds of the kitchens were collected when there were no observed activities in the kitchens. The equipment inlets were placing directly above the cooking appliance and at height about 1.5m which is approximately near the breathing height of human being.

3.2.3 Sampling Instrumentation

The TSI Model 8525 P Trak ultrafine particle (smaller than 0.1 micron diameter) counter (TSI Incorporated, St. Paul, MN, USA) was used to measure real-time particle concentrations, in particles per cubic centimeter (pt/cc). Upon entering the instrument, particles mixed with an alcohol vapor. Then the alcohol condensed on particles causing them to grow into droplets that can be counted. After passing through a focused laser beam, the light flashes are sensed by photodetector and then particle number concentrations are determined. The concentration range of P trak is $0\sim5x10^5$ pt/cc, however the particles generated from frying usually exceeded this range. As a result, dilution should be done to the instrument by reducing the flowrate.

Met One 9012 Ambient Aerosol Particulate Profiler (Met One) is a low flow (2.83 Litre/min) optical light scatter PM monitoring machine that used a laser diode based optical sensor to convert scattered light to numbers of particles per size range. As a PM monitor, particles are detected, sized and counted in six size ranged from 0.3 to 10 μm which can be selected. In addition, the sampling time intervals can as low as 2 seconds to quantify rapid changes in aerosol concentration.

The TSI Model 8520 Dust Trak aerosol monitor (TSI Incorporated, St. Paul, MN, USA), with a 2.5μm inlet was used to measure the real-time approximation of $PM_{2.5}$ concentration. It should be noted that the Dust Trak operates based on a light scattering technique where the amount of scattered light is proportional to the volume concentration of the aerosol (Morawska, et al., 2003). The $PM_{2.5}$ values obtained in this study using Dust Trak are not actual gravimetric values. However, it was compared with gravimetric methods to obtain a correction factor in order to get a better estimation of $PM_{2.5}$.

An Omni personal sampling pump (BGI Inc) with $PM_{2.5}$ cyclone was used to collect $PM_{2.5}$ by drawing air at a flow rate of 5 liter per minute. A 47mm Teflon filter was placed in this sampler to collect air samples. The filters were equilibrated in a dessiccator at a constant temperature of 25ºC and relative humidity of 35% for at least 24 hours before and after exposure. The filters were then weighted with a Microbalance (Model MC5, Sartorius AG, Goettingen. Germany) with the sensitivity of ±1 μg in 0-250 mg range. All filters were placed inside plastic Petri dishes, and then all Petri dishes were placed inside a sealed plastic bag and stored inside the

icebox at -4˚C.

The TSI Model 8554 Q Trak (TSI Incorporated, St. Paul, MN, USA) monitor simultaneously measures CO_2, CO, temperature and humidity, all within a single probe. CO_2 is measured to calculate the air exchange rate in the kitchen.

3.2.4 Calculation of Air Exchange Rate (AER)

The tracer gas technique involves injecting a tracer gas and mixing it through the house, then measuring its decay rate with an appropriate instrument. If exfiltration rates of the tracer gas are constant, mixing is uniform, the chemicals are negligible and no indoor source of the gas is operating, the AER a, can be calculated from the following equation (Nantka, 1990):

$$a = \frac{1}{t} \ln \frac{C_t}{C_0} \qquad (1)$$

Where t is time, C_t and C_0 are concentrations of the gas at times t and 0, respectively. Equation 1 was used to calculate the AER of the kitchen in the residential dwellings in this study based on measured CO_2 decay rates.

3.2.5 Source Emission Rate and Emission factor

To calculate the source emission rates, the mass balance differential equation taking into consideration of indoor and outdoor particle sources, deposition rate of particles on indoor surfaces, and AER is applied. (Koutrakis et al., 1992; Chen et al.,

2000):

$$\frac{dC_{in}}{dt} = P\alpha C_{out} - (\alpha + K)C_{in} + \frac{Q_s}{V} \quad (2)$$

Where C_{in}= indoor mass or number concentration of particle (mg/m^3 or pt/cc), C_{out}= outdoor mass or number concentration of particle (mg/m^3 or pt/cc), P is the penetration coefficient across building envelope, a= air exchange rate (h^{-1}), K= K_1+K_2, K_1 is the natural decay rate of the particle when the stove is turned off, and K_2 is the additional decay rate when the fan is on, V= efficient volume of the building (m^3), Qs= indoor particle generation rate (mg/hr or pt/hr), t= time (hr). Many previous studies (Ott, 1999) discussed the use of this equation for determination of the source strength of indoor pollutants. It is understood that the equation refers to a particular aerosol size, and that P, K, and Qs may all be function of particle size. In order to calculate the source emission rate, some assumptions should be made:

1. the kitchen is considered to be a single well-mixed zone with instantaneous mixing;
2. the penetration efficiency P is assumed to close to one for both fine and coarse particles;
3. Before cooking is taking place in the kitchen, the indoor concentration is equal to outdoor concentration and the initial indoor particle concentration (C_0) can be replaced by outdoor particle concentration.

Applied all these assumptions and solving for Q_s

$$Q_S = \frac{V(\alpha + k)\Delta C_{in}}{[1 - \exp(-(\alpha + k)\Delta t)]} \quad (3)$$

This equation ignores the effects of processes involving particles, such as condensation, evaporation or coagulation, since these are minor effects under particle concentrations and conditions normally encountered in residential environments (Thatcher and Layton, 1995). In order to determine the Q_s, The decay rate a+k should be determined first. This is done by determining the background concentration, subtracting the background from all of the elevated values following cooking, transforming to logarithms, and carrying out a regression analysis over time. The negative slope of the regression is a+k.

3.2.6 Quality Assurance and quality control

To ensure the samples collected were consistency to have any conclusion, at least 4 sets of sampling were done with different cooking styles. To ensure accurate measurement of the air quality, all monitoring instruments should be checked for zero and span before sampling, and also calibrated and certified in accordance with the manufacturers' recommendations.

Before sampling, the Q-Trak was calibrated with standard CO_2 gas at a known concentration. Pre and post zero checking of the Dust Trak monitor was carried out.

Chapter 4

Results and Discussion

4. Results and discussion

4.1 Commercial Restaurants

A total of 48 samples were collected in this study. For each restaurant, four lunch samples, one background sample and one blank sample were collected.

4.1.1 Data validation

4.1.1.1 Sum of Chemical Species versus Mass

The sum of the individual chemical concentrations for $PM_{2.5}$ should be less than or equal to the corresponding gravimetrically measured mass concentrations. This sum includes chemicals quantified on the Teflon-membrane and quartz-fiber filters. Total sulfur (S), soluble chloride (Cl^-), and soluble potassium (K^+) are excluded from the sum to avoid double counting since sulfate (SO_4^{2-}), chlorine (Cl), and total potassium (K) are included in the sum. Measured concentrations do not account for unmeasured metal oxides in crustal material, unmeasured cations, or hydrogen and oxygen associated with organic carbon.

The composition of chemical species concentrations measured by different chemical analysis methods was examined. Physical consistency was tested for: 1) sulfate versus total sulfur, 2) chloride versus chlorine, and 3) soluble potassium versus total potassium.

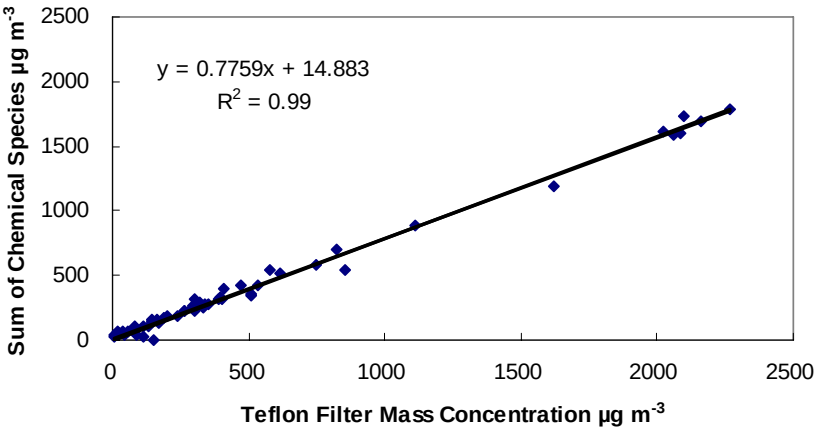


Figure 4-1-1 Scatter plots of sum of species versus mass measurements from $PM_{2.5}$ data acquired for all valid sample (n=48)

Figure 4-1-1 shows scatter plots of the $PM_{2.5}$ sum of species versus mass for all samples collected in commercial restaurants and residential dwellings. Each point contains a solid line indicating the slope with intercept. Regression statistics with mass as the independent variable (X) and sum of species as the dependent variable (Y) are calculated. The calculated correlation coefficients are also shown. As shown in Figure 4-1-1, all of the sums are less than the corresponding $PM_{2.5}$ mass. A good relationship was found between the sum of species and mass, with correlation coefficients exceeding 0.99 for all measurements.

4.1.1.2 Physical Consistency

Sulfate versus Total Sulfur

Water-soluble (SO_4^{2-}) was measured by ion chromatography (IC) analysis on

quartz-fiber filters, and total sulfur (S) was measured by XRF analysis on Teflon-membrane filters. The ratio of sulfate to total sulfur should equal "3" if all of the sulfur were present as soluble sulfate. Figure 4-1-2 shows scatter plots of sulfate versus sulfur concentrations for all samples. A good correlation (linear correlation coefficient R^2=0.949) was found among $PM_{2.5}$ sulfur/sulfate measurements. The regression statistics give a slope of 3.02.

Overall, the sulfate and total sulfur comparisons in the present study support the contentions that more than 90% of sulfur was present as soluble sulfate in the kitchen exhaust and that both XRF and IC measurements are valid.

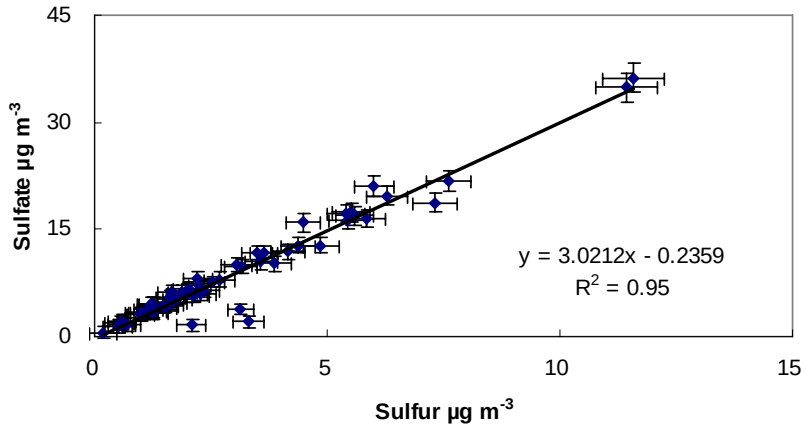


Figure 4-1-2 Scatter plots of sulfate versus sulfur measurements from $PM_{2.5}$data acquired at all sampling sites (n=48)

Chloride versus Chlorine

Chloride (Cl^-) was measured by IC on quartz-fiber filters, and chlorine (Cl) was

measured by XRF on Teflon-membrane filters. Because chloride is the water-soluble portion of chlorine, the chloride-to-chlorine ratio is expected to be less than unity. Figure 4-1-3 shows that high correlation (R^2=0.9627) was found between $PM_{2.5}$ chloride and chlorine measurements, with a slope close to 0.8. This relatively low slope may attribute to the low chloride concentration, which is close to the detection limit. As a result, larger errors was observed.

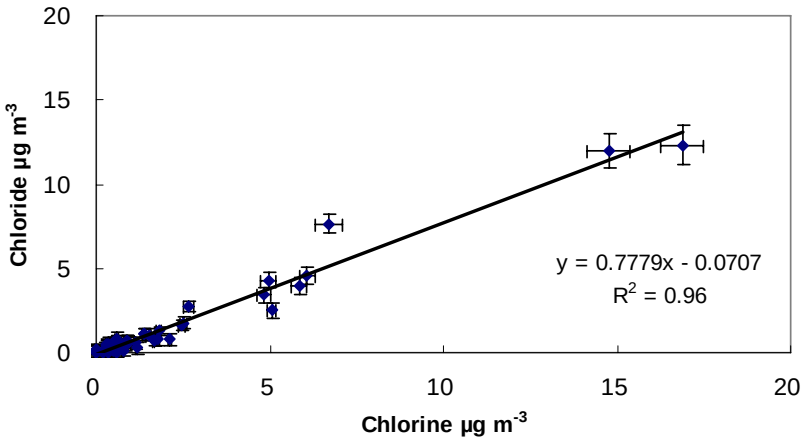


Figure 4-1-3 Scatter plots of chloride versus chlorine measurements from $PM_{2.5}$ data acquired at all sampling sites (n=48)

Soluble Potassium versus Total Potassium

Soluble potassium (K^+) was acquired by atomic absorption spectrophotometry (AAS) analysis on quartz-fiber filters, and total potassium (K) was acquired by XRF analysis on Teflon-membrane filters. Figure 4-1-4 displays the scatter plots of soluble potassium versus total potassium concentrations. It shows that good correlation (R^2=0.9364) was found between $PM_{2.5}$ soluble potassium and total potassium

measurements. The regression statistics give a slope near to unity which means that nearly all potassium is in its soluble state. This analysis also shows that K^+ concentrations are low to moderate throughout the study area.

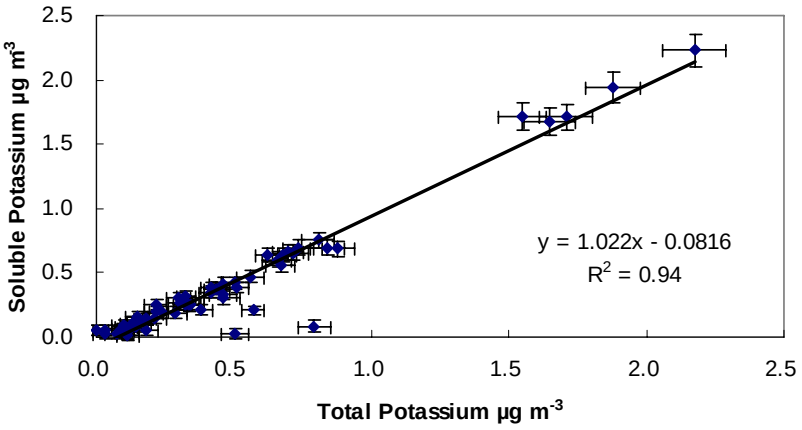


Figure 4-1-4 Scatter plots of total potassium versus soluble potassium measurements from $PM_{2.5}$ data acquired at all sampling sites (n=48)

Ammonium Balance

Ammonium nitrate (NH_4NO_3), ammonium sulfate ($[NH_4]_2SO_4$), and ammonium bisulfate (NH_4HSO_4), are the most likely nitrate and sulfate compounds to be found in Hong Kong. Ammonium (NH_4^+) can be calculated based on the stoichiometric ratios of the different compounds and compared with that which was measured. In Figure 4-1-5, ammonium is calculated from nitrate and sulfate, assuming that all nitrate was in the form of ammonium nitrate and all sulfate was in the form of either ammonium sulfate (i.e., calculated ammonium = [0.38 x sulfate] + [0.29 x nitrate]) or ammonium bisulfate (i.e., calculated ammonium = [0.192 x sulfate] + [0.29 x nitrate]). These

calculated values were compared with the measured values for ammonium.

Figure 4-1-5 shows very good agreement for $PM_{2.5}$ ammonium with correlation coefficients exceeding 0.95 when ammonium sulfate or ammonium bisulfate was assumed. However, the slopes found in these figures were 1.3844 when assuming ammonium bisulfate and 0.8915 when assuming ammonium bisulfate.

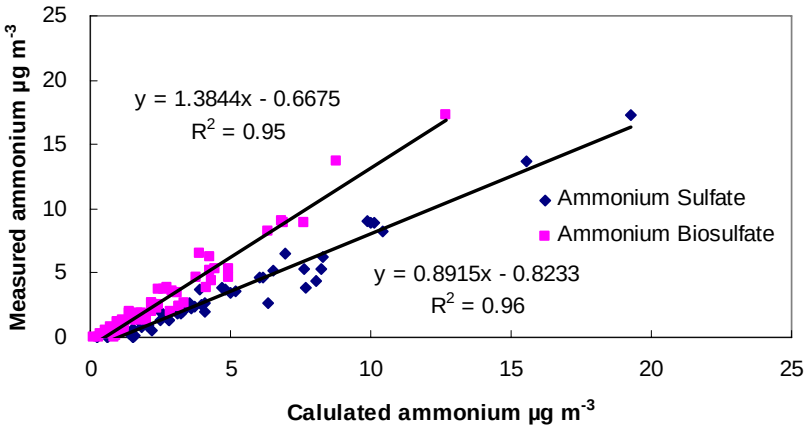


Figure 4-1-5 Scatter plots of calculated ammonium versus measured ammonium from $PM_{2.5}$ data acquired at all sampling sites (n=48)

4.1.1.3 Anion and Cation Balance

The anion and cation balance (Chow, et al., 2002) were calculated according to the following equations.

1) Anion Equivalence = $Cl^-/35.453 + NO_3^-/62.005 + SO_4^{2-}/48.03$

2) Cation Equivalence = $Na^+/23.0 + K^+/39.098 + NH_4^+/18.04$

Figure 4-1-6 also shows a deficiency in cations that is not accounted for by measured anions. The correlations are high (R^2= 0.9595) for $PM_{2.5}$ size fractions.

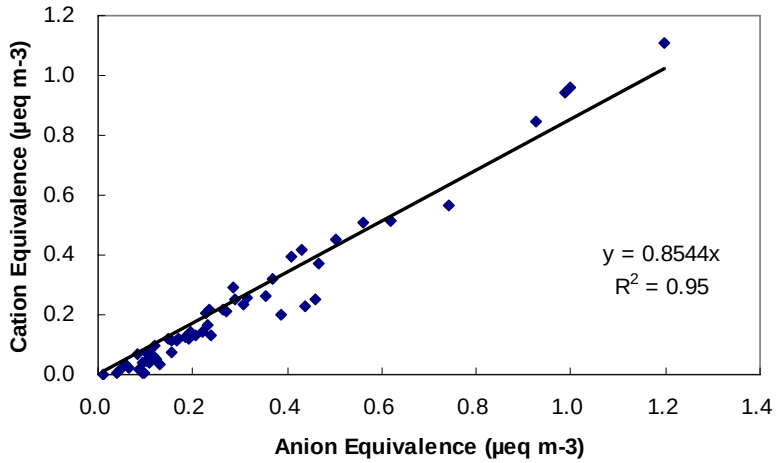


Figure 4-1-6 Scatter plots of cation versus anion measurements from $PM_{2.5}$ data acquired at all sampling sites (n=48)

4.1.1.4 Reconstructed versus Measured Mass

Major PM components can be used to reconstruct PM mass (Chow, et al. 2002). The major components include:

1) geological material (estimated as 1.89 × Al + 2.14 × Si+ 1.4 × Ca + 1.43 × Fe);
2) organic matter (OM: 1.2 × OC to account for unmeasured hydrogen and oxygen);
3) soot (elemental carbon);
4) ammonium sulfate;
5) ammonium nitrate; and
6) noncrustal trace elements (sum of other-than-geological trace elements).

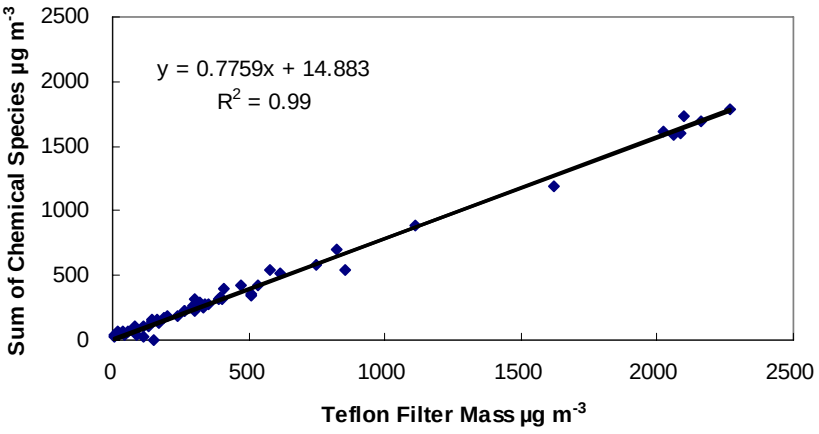


Figure 4-1-7 Scatter plots of reconstructed mass versus measured mass from $PM_{2.5}$ data acquired at all sampling sites (n=48)

To measure the gravimetric mass, Teflon filters were weighted at 30%-40% relative humidity. There could, however, still be residual water that accounted for the unidentified mass. Overall, the reconstructed mass accounts for about 78% of the Teflon filter mass.

The difference between the constructed mass and the measured mass is referred to as unidentified mass. The reconstructed mass are highly correlated to the measured mass at R^2 ~ 0.99 (Figure 4-1-7). In contrast to the sum-of-species-versus-mass comparison, unaccounted mass is largely eliminated when unmeasured oxygen and hydrogen were factored in.

4.1.2 $PM_{2.5}$ mass concentration and chemical species

4.1.2.1 $PM_{2.5}$ mass concentration

In this study, quartz filter will be used in parallel with polyolefin-ringed Teflon filter downstream of the cyclone used to remove particles greater than 2.5 micron diameter.

The characterization of Teflon-membrane filter collected particles were analyzed for mass by gravimetry and elemental analysis (40 elements including Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pb, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, and U) by x-ray flouresence (Watson et al., 1999). The quartz-fiber filter, which is also a 47-mm diameter filter, was analyzed for chloride (Cl^-), nitrate (NO^{3-}), and sulfate (SO_4^{2-}), by ion chromatography (Chow and Watson, 1999). Ammonium (NH_4^+) was analyzed by automated colorimetry. Water-soluble sodium (Na^+) and potassium (K^+) was analyzed by atomic spectrophotometry, and for carbon by two thermal evolution methods.

On average, the mass concentrations of $PM_{2.5}$ for all measurements in commercial restaurants were 514.2±148.5 μg m^{-3} (CR 1), 1205.1±588.2 μg m^{-3} (CR 2), 1135.1±101μg m^{-3} (WR 1), 281.8±114.1 μg m^{-3} (WR 2), 2100.45±94.0 μg m^{-3} (FR 1) and 298.39±45.89 μg m^{-3} (FR 2). (Table 4-1-1). In terms of mass concentration levels and assigning the sites in descending order with site characteristics, it is observed that FR 1>CR 2> CR 1>FR 2>WR 2>WR 1. FR 1 generated nearly 9 times more $PM_{2.5}$ than that of WR 1. Figure 4-1-8 displays $PM_{2.5}$ levels at six commercial restaurants. This figure indicates that WR2 has the highest $PM_{2.5}$ variation, this is because WR2 is

larger than other restaurants. As a result, the types of food served, number of customers vary dramatically.

The mean ambient fine particle mass concentration in Hong Kong was measured to be around 50 μg m^{-3}. As a result, the concentrations of $PM_{2.5}$ in cooking emissions were roughly two or three orders of magnitude than the ambient concentration.

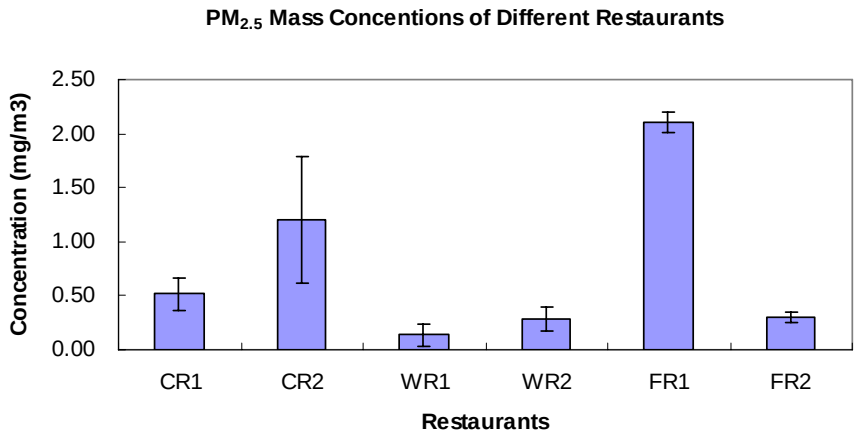


Figure 4-1-8 Mean mass concentrations of $PM_{2.5}$ in each restaurant

The two Chinese restaurants have similar cooking methods, that is, steaming dim sum and frying. Frying is found to be producing more particle than other cooking methods (Abt et al., 2000; Lee et al., 2001; Li et al., 2003). As a result, $PM_{2.5}$ concentrations in Chinese restaurants were relatively high.

The main cooking styles in two fast food restaurants are similar, that is, deep frying. However, $PM_{2.5}$ concentrations differ dramatically. FR 2 has much lower $PM_{2.5}$ concentrations. As people in this restaurant are more likely to have food like,

salad, steaming rice… which was not prepared by deep frying and generate relatively less or even no cooking oil fumes. Thus, a low PM concentration was observed.

From the figure above, it can be concluded that western restaurants generally emit less $PM_{2.5}$ when compared to Chinese and Fast Food restaurants. However, it should be noted that the measurements in this study are only conducted in limited representative restaurants, i.e. the emission of only two restaurants for each type were estimated. However, the emission from commercial restaurants would be affected by many factors, for example, the food served by the restaurant, the size of restaurant, the number of customers…etc. Therefore the conclusion that western restaurants emit less $PM_{2.5}$ can only provide a general idea with a high degree of uncertainty.

A study conducted in Shenzhen (He et al., 2004) found that fine particle mass concentrations were measured to be 1406.3 ± 293.4 μg m^{-3} and 672.0 ± 295.8 μg m^{-3} in Hu nan cooking and Cantonese cooking, respectively. The results were comparable to those measured in this study, although the location and size of the restaurants, food served were different.

4.1.2.2 $PM_{2.5}$ chemical species

In this study, quartz filters will be used to collect samples for organic and elemental carbon analysis (using TOR and TOT methods) and for water soluble inorganic ions (by IC).

The composition of the fine particulate matter generated from all sampled restaurants is shown in Table 4-1-1, Table 4-1-2 and Table 4-1-3.

Table 4-1-1 Fine particle chemical compositions emitted from Chinese restaurants

	Chinese Restaurant	
	CR 1	**CR 2**
Mass Concentration ($\mu g\ m^{-3}$)	514.2±148.5	1205.1±588.2
	Particle Composition	
Organic carbon (wt%)	76.9	73.6
Elemental carbon (wt%)	2.9	1.0
Cl^- (wt%)	0.3	0.6
NO_3^- (wt%)	0.6	0.2
SO_4^{2-} (wt%)	0.8	0.5
NH_4^+ (wt%)	0.4	0.1
Na^+ (wt%)	0.3	0.5
K^+ (wt%)	0.0	0.1
Mg^{2+} (wt%)	0.0	0.0
Ca^{2+} (wt%)	0.0	0.0

Table 4-1-2 Fine particle chemical compositions emitted from western restaurants

	Western Restaurant	
	WR 1	**WR 2**
Mass Concentration (μg m^{-3})	135.1±101	281.8±114.1
	Particle Composition	
Organic carbon (wt%)	75.7	91.2
Elemental carbon (wt%)	1.9	5.2
Cl^- (wt%)	0.3	0.2
NO_3^- (wt%)	0.4	0.1
SO_4^{2-} (wt%)	0.9	1.6
NH_4^+ (wt%)	0.2	0.2
Na^+ (wt%)	0.2	0.2
K^+ (wt%)	0.1	0.1
Mg^{2+} (wt%)	0.0	0.0
Ca^{2+} (wt%)	0.0	0.0

Table 4-1-3 Fine particle chemical compositions emitted from fast food restaurants

	Fast Food Restaurant	
	FR 1	**FR 2**
Mass Concentration (μg m^{-3})	2100.45 ± 94.0	298.39 ± 45.9
	Particle Composition	
Organic carbon (wt%)	98.7	93.5
Elemental carbon (wt%)	0.9	4.2
Cl^- (wt%)	0.0	0.0
NO_3^- (wt%)	0.1	0.2
SO_4^{2-} (wt%)	0.2	1.2
NH_4^+ (wt%)	0.0	0.2

Na^+ (wt%)	0.0	0.0
K^+ (wt%)	0.0	0.0
Mg^{2+} (wt%)	0.0	0.0
Ca^{2+} (wt%)	0.0	0.0

From above three tables, as expected, the aerosol is predominately organic matter consisting of organic carbon (OC) in all commercial restaurants. Organic carbon contributed 76.9% and 73.6% in Chinese restaurant 1 and Chinese restaurant 2, 75.7% and 91.2% in western restaurant 1 and western restaurant 2, and 98.7% and 93.5% in fast food restaurant 1 and fast food restaurant 2. Organic carbon contributed over 90% in both fast food restaurants. As the main cooking style in both fast food restaurants was deep frying, this indicates that the fraction of organic carbon is extremely high in the fine particle mass emitted by deep frying.

He (He et al., 2004) also reported that organic carbon was the main constituent in the $PM_{2.5}$ mass, 81.6% and 52.6% organic carbon in Hunan cooking and Cantonese cooking, respectively. Schauer (Schauer et al., 1999) found that organic carbon contributed 33.8% during meat charbroiling. Schauer (Schauer et al., 2002) also presented organic carbon constituted the largest fraction of $PM_{2.5}$ emissions from vegetables stir-fried in soybean oil, in canola oil and deep frying of potatoes, accounting for approximately 69.6%, 58.3% and 62.7% of the fine particle mass. For organic carbon, the fraction measured in study is generally higher than those previous works measured in China and U.S.A. Due to the difference in food cooked as well as cooking styles, variations of organic carbon's fraction were anticipated and indeed observed among cooking studies in different parts of the world.

Elemental carbon was also measured in the fine particle emissions but the concentrations were low, it made up of about 0.9%~5.2% of the fine particle mass.

Several ionic species also were measured in the fine particle emissions at lower but noticeable percentages. In both Chinese restaurants, sodium, nitrate ion, sulfate and chloride all made up about 0.5% of the fine particle mass. SO_4^{2-} was found to contribute 0.9% and 1.6% of the fine particle mass in WR 1 and WR 2, respectively. These ionic species are believed to be derived from the raw food and the cooking sauces.

One way to illustrate the overall material balance or chemical composition in the $PM_{2.5}$ particulate is to account for other species including crustal materials, soluble ions and trace species. A typical approach to obtain a rough mass balance of the sampled $PM_{2.5}$ particulate is to adjust OC for missing hydrogen and oxygen atoms in order to find organics (or organic matter) and major elements including Al, Fe, Ca, and Si for missing oxygen atoms. If the organic carbon reported in the above tables is converted to organic compound mass with the estimated factor of 1.4, the sum of the measured species accounts for the entire mass of the particulate matter for all sampled restaurants. However, a factor of 1 was used. Other species including Fe, Ca, Si, and Al are adjusted by multiplying by 1.43 for an estimate of Fe_2O_3, 1.4 for an estimate of CaO, and 2.14 for an estimate of SiO_2, and 1.89 for Al (Solomon et al., 1989). The pie charts of material balance calculation for chemical components of $PM_{2.5}$ at commercial restaurants are presented in figure 4-1-9.

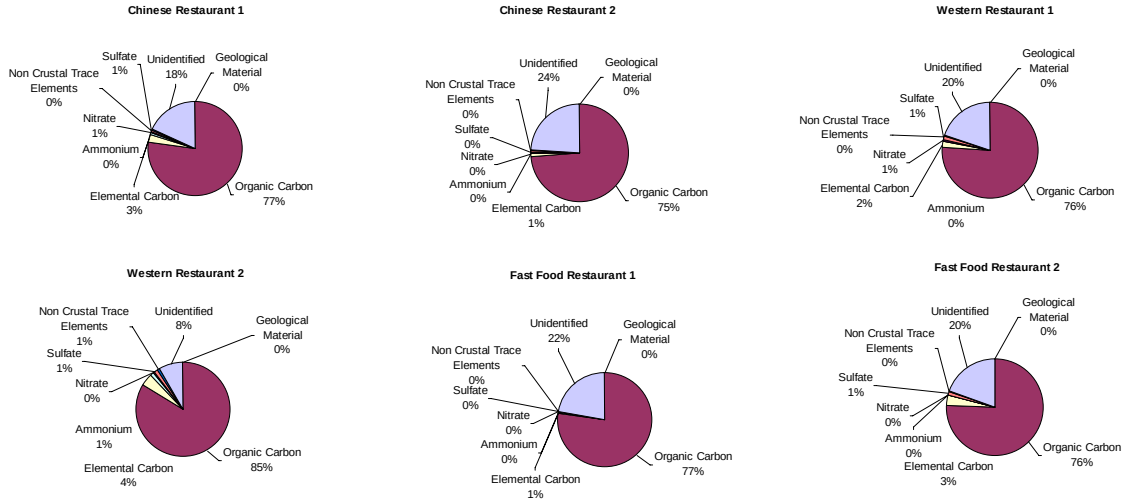
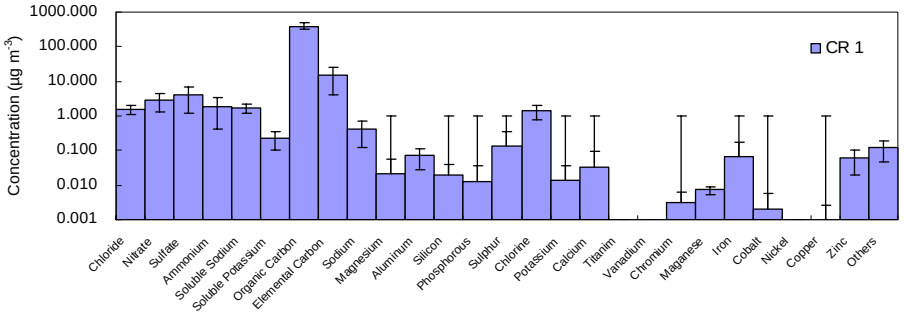


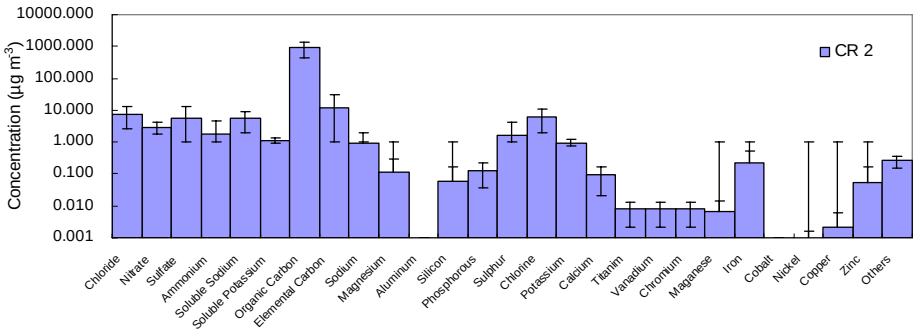
Figure 4-1-9 Chemical components measured for $PM_{2.5}$ in commercial restaurants

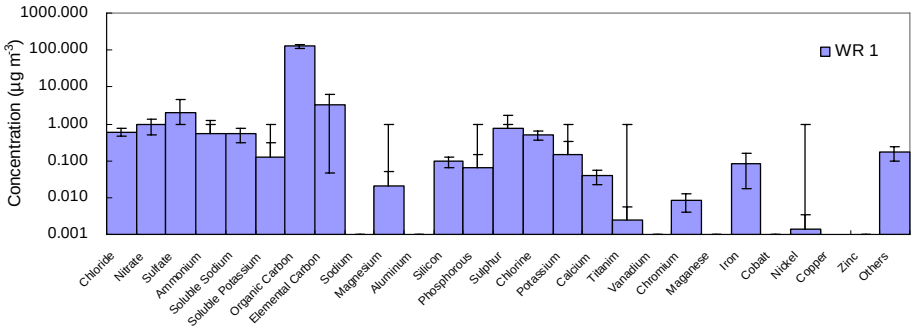
It shows the abundance of different composition for all samples measured within commercial restaurants. Figure 4-1-9 does not show significant differences in emission patterns among different types of restaurants. OC is the most abundant species found at all sampling sites. Other chemical species only contribute a minor portion to the total $PM_{2.5}$ mass. However, the percentages of "unidentified" species are also high, which is the second abundant groups. This may attribute to the missing hydrogen and oxygen atoms of organics, as the converting factor of OC to organics used in study is 1.

It is noted that the mean concentrations of organic carbons varied greatly among different commercial restaurants. On average, the concentrations of OC for all measurements in commercial restaurants were 398.64±100.9 μg m^{-3} (CR 1), 894.15±499.0 μg m^{-3} (CR 2), 127.65±22.5μg m^{-3} (WR 1), 228.56±71.4 μg m^{-3} (WR 2), 1597.95±79.0 μg m^{-3} (FR 1), 207.82±35.7 μg m^{-3} (FR 2) (Table 4-1-4). In terms of OC concentration levels and assigning the sites in descending order, it is observed that FR 1>CR 2> CR 1>FF 2>WR 2>WR 1. Generally speaking, Western restaurants emit less organic carbon when compared to Chinese and Fast Food restaurants.

The chemical profiles of $PM_{2.5}$ mass at commercial restaurants are shown in Figure 4-1-10. The concentrations of all chemical species were presented in table 4-1-4.


1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Concentration (µg m-3)
CR 1
Chloride
Nitrate
Sulfate
Ammonium
Soluble Sodium
Soluble Potassium
Organic Carbon
Elemental Carbon
Sodium
Magnesium
Aluminum
Silicon
Phosphorous
Sulphur
Chlorine
Potassium
Calcium
Titanim
Vanadium
Chromium
Maganese
Iron
Cobalt
Nickel
Copper
Zinc
Others


10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Concentration (µg m-3)
CR 2
Chloride
Nitrate
Sulfate
Ammonium
Soluble Sodium
Soluble Potassium
Organic Carbon
Elemental Carbon
Sodium
Magnesium
Aluminum
Silicon
Phosphorous
Sulphur
Chlorine
Potassium
Calcium
Titanim
Vanadium
Chromium
Maganese
Iron
Cobalt
Nickel
Copper
Zinc
Others


1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Concentration (µg m-3)
WR 1
Chloride
Nitrate
Sulfate
Ammonium
Soluble Sodium
Soluble Potassium
Organic Carbon
Elemental Carbon
Sodium
Magnesium
Aluminum
Silicon
Phosphorous
Sulphur
Chlorine
Potassium
Calcium
Titanim
Vanadium
Chromium
Maganese
Iron
Cobalt
Nickel
Copper
Zinc
Others

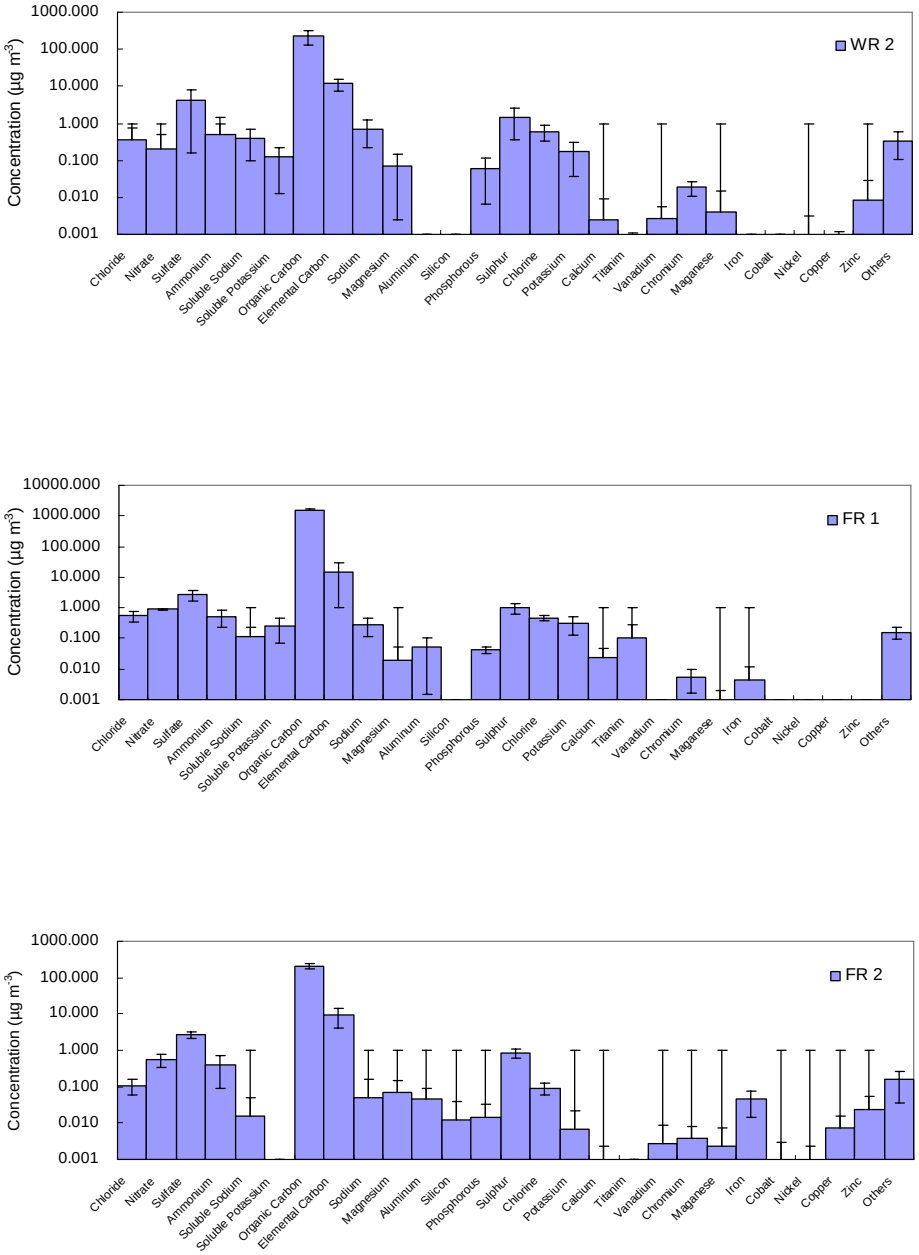


Figure 4-1-10 The mean chemical profile of total measured chemical species at commercial restaurants

Table 4-1-4 Average concentration of Chemical species in commercial restaurants

Site	CR 1 (μgm^{-3})			CR 2 (μgm^{-3})			WR 1 (μgm^{-3})			WR 2 (μgm^{-3})			FR 1 (μgm^{-3})			FR 2 (μgm^{-3})		
	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
Chloride	1.56	4	0.51	7.72	5	5.21	0.48	4	0.22	0.37	7	0.35	0.56	4	0.21	0.11	6	0.05
Nitrate	2.86	4	1.59	2.9	5	1.15	0.7	4	0.55	0.13	7	0.32	0.88	4	0.03	0.55	6	0.22
Sulfate	3.93	4	2.74	5.49	5	7.53	1.49	4	2.5	3.59	7	3.82	2.69	4	1.1	2.67	6	0.61
Ammonium	1.85	4	1.42	1.77	5	2.77	0.4	4	0.69	0.54	7	0.9	0.51	4	0.28	0.41	6	0.32
Soluble Sodium	1.66	4	0.48	5.68	5	3.63	0.41	4	0.27	0.42	7	0.28	0.11	4	0.12	0.02	6	0.03
Soluble Potassium	0.22	4	0.12	1.16	5	0.21	0.09	4	0.16	0.12	7	0.1	0.26	4	0.18	0	6	0
Organic Carbon	398.64	4	100.84	894.15	5	499.04	127.65	4	22.48	228.56	7	71.41	1597.95	4	78.98	207.82	6	35.66
Elemental Carbon	14.91	4	12.33	11.97	5	19.59	3.22	4	3.88	11.67	7	1.88	14.22	4	16.95	9.42	6	5.98
Sodium	0.41	4	0.29	0.89	5	1.14	0	4	0	0.78	7	0.48	0.28	4	0.17	0.05	6	0.11
Magnesium	0.02	4	0.04	0.12	5	0.17	0.03	4	0.04	0.08	7	0.07	0.02	4	0.03	0.07	6	0.07
Aluminum	0.07	4	0.04	0	5	0	0	4	0	0.00	7	0	0.05	4	0.05	0.04	6	0.05
Silicon	0.02	4	0.02	0.06	5	0.11	0.07	4	0.05	0.00	7	0	0	4	0	0.01	6	0.03
Phosphorous	0.01	4	0.02	0.13	5	0.09	0.05	4	0.08	0.05	7	0.06	0.04	4	0.01	0.01	6	0.02
Sulphur	0.13	4	0.23	1.7	5	2.36	0.55	4	0.94	1.11	7	1.42	1	4	0.35	0.85	6	0.25
Chlorine	1.42	4	0.65	6.21	5	4.23	0.38	4	0.24	0.56	7	0.26	0.47	4	0.09	0.09	6	0.03
Potassium	0.01	4	0.02	0.95	5	0.22	0.11	4	0.18	0.17	7	0.13	0.32	4	0.19	0.01	6	0.01
Calcium	0.03	4	0.06	0.09	5	0.07	0.03	4	0.02	0.00	7	0.01	0.02	4	0.03	0	6	0
Titanim	0	4	0	0.01	5	0.01	0	4	0	0.00	7	0	0.11	4	0.16	0	6	0
Vanadium	0	4	0	0.01	5	0.01	0.01	4	0.01	0.00	7	0	0	4	0	0	6	0.01
Chromium	0	4	0	0.01	5	0.01	0.01	4	0.01	0.02	7	0.01	0.01	4	0	0	6	0
Maganese	0.01	4	0	0.01	5	0.01	0	4	0	0.00	7	0.01	0	4	0	0	6	0.01

Site	CR 1 (μgm^{-3})			CR 2 (μgm^{-3})			WR 1 (μgm^{-3})			WR 2 (μgm^{-3})			FR 1 (μgm^{-3})			FR 2 (μgm^{-3})		
	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
Iron	0.07	4	0.1	0.23	5	0.29	0.06	4	0.07	0.00	7	0	0	4	0.01	0.05	6	0.03
Cobalt	0	4	0	0	5	0	0	4	0	0.00	7	0	0	4	0	0	6	0
Nickel	0	4	0	0	5	0	0	4	0	0.00	7	0	0	4	0	0	6	0
Copper	0	4	0	0	5	0	0	4	0	0.00	7	0	0	4	0	0.01	6	0.01
Zinc	0.06	4	0.04	0.06	5	0.11	0	4	0	0.01	7	0.02	0	4	0	0.02	6	0.03
Gallium	0.03	4	0.02	0.02	5	0.03	0	4	0	0.02	7	0.02	0	4	0	0.01	6	0.02
Arsenic	0	4	0	0	5	0	0	4	0	0.00	7	0	0	4	0	0	6	0
Selenium	0	4	0	0	5	0	0	4	0	0.00	7	0	0	4	0	0	6	0
Bromine	0.01	4	0.01	0.01	5	0.01	0.02	4	0.01	0.01	7	0.01	0.01	4	0.01	0	6	0
Rubidium	0	4	0	0	5	0	0	4	0	0.00	7	0	0	4	0	0	6	0.01
Strontium	0.01	4	0.01	0	5	0	0	4	0.01	0.01	7	0.01	0.02	4	0.01	0	6	0.01
Yttrim	0	4	0	0	5	0	0	4	0	0.00	7	0.01	0	4	0	0.01	6	0.01
Zirconium	0	4	0.01	0	5	0.01	0	4	0	0.00	7	0	0	4	0	0.01	6	0.02
Molybdenum	0	4	0	0.01	5	0.01	0	4	0	0.00	7	0.01	0	4	0	0	6	0
Palladium	0.01	4	0.02	0	5	0	0.01	4	0.01	0.01	7	0.02	0.02	4	0.02	0.01	6	0.01
Silver	0	4	0	0	5	0	0.02	4	0.02	0.02	7	0.03	0	4	0.01	0	6	0
Cadmium	0	4	0	0.05	5	0.02	0	4	0	0.03	7	0.02	0.01	4	0.02	0.01	6	0.02
Indium	0.01	4	0.01	0.01	5	0.01	0	4	0	0.02	7	0.03	0	4	0	0	6	0
Tin	0	4	0	0	5	0	0.03	4	0.02	0.00	7	0	0.01	4	0.02	0	6	0
Antimony	0.01	4	0.02	0.01	5	0.02	0.02	4	0.03	0.01	7	0.01	0	4	0.01	0.02	6	0.02
Barium	0.01	4	0.02	0	5	0	0.01	4	0.02	0.00	7	0.01	0.03	4	0.06	0.01	6	0.01
Lanthanum	0.03	4	0.05	0.08	5	0.1	0.08	4	0.1	0.21	7	0.19	0.02	4	0.02	0.05	6	0.08
Gold	0	4	0	0.01	5	0.02	0.01	4	0.02	0.00	7	0	0.03	4	0.02	0.01	6	0.02

Site	CR 1 (μgm^{-3})			CR 2 (μgm^{-3})			WR 1 (μgm^{-3})			WR 2 (μgm^{-3})			FR 1 (μgm^{-3})			FR 2 (μgm^{-3})		
	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
Mercury	0	4	0	0	5	0.01	0	4	0	0.00	7	0	0	4	0	0	6	0.01
Thallium	0	4	0	0	5	0	0	4	0	0.01	7	0.01	0	4	0	0	6	0
Lead	0	4	0	0.04	5	0.04	0	4	0	0.02	7	0.01	0	4	0	0	6	0
Uranium	0	4	0	0.01	5	0.01	0.02	4	0.02	0.02	7	0.03	0	4	0	0.02	6	0.02

* S.D: standard deviation
* CR: Chinese Restaurant; WR: Western Restaurant; FR: Fast Food restaurant;
* N: Number of samples

4.1.3 Organic Compound Emissions

4.1.3.1 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are one of the first identified airborne carcinogenic pollutants containing two or more aromatic rings that are fused together in different arrangements (Beak et al., 1991). These organic compounds are produced by high-temperature reactions, such as incomplete combustion and pyrolysis of fossil fuels and other organic materials (Nicolaou et al., 1984). Chiang et al. (1999) also indicated that PAHs were formed mainly by unsaturated fatty acid, which is oxidized at high temperature through two processes: pyrolysis and pyrosynthesis.

22 particulate and gaseous PAH species were identified in this study. Table 4-1-5 shows the mean PAH concentrations (gaseous phase+ particle phase) emitted from six commercial restaurants. The magnitudes of total measured PAH concentrations (gaseous phase + particle phase) for the six restaurants were WR2 ($7.84 \pm 3.60 \mu g\ m^{-3}$) > CR1 ($3.78 \pm 1.70\ \mu g\ m^{-3}$) > CR2 ($2.85 \pm 0.63\ \mu g\ m^{-3}$) > FR1 ($2.66 \pm 0.74\ \mu g\ m^{-3}$) > FR2 ($1.53 \pm 0.96 \mu g\ m^{-3}$) > WR1 ($1.14 \pm 0.23 \mu g\ m^{-3}$). Li (Li et al., 2003) reported that the magnitude of total PAH concentrations for four types of restaurants were Western ($92.9 \mu g\ m^{-3}$) > Chinese ($80.1 \mu g\ m^{-3}$) > fast food ($63.3 \mu g\ m^{-3}$) >Japanese ($55.5\ \mu g\ m^{-3}$). The total measured PAHs concentrations in that study in that study is over 10-fold higher than that of in this study. The difference was probably derived from various food ingredients and different size of the restaurant. WR2 has the highest PAH emission while WR1 has the lowest. This may attribute to the sampling site at WR2.

Sampling site at WR2 is in an outdoor environment near a roadside. As a result, the PAH emission was affected by traffic, because vehicle has long been recognized as a main contributor of PAHs. However, the trend for total PAH concentration found in these two studies is similar.

Many other studies have been conducted to investigate the PAH compositions from cooking processes. Siegmann and Sattler (Siegmann and Sattler., 1996) found that in hot cooking oil fumes, PAH concentrations ranged from 1.08-22.8 μg m^{-3}. It is also reported that charbroiling emissions yield 3-5 times more PAHs than the meats cooked on the griddle (Mcdonald et al., 2003). Another study (He et al., 2004) conducted in Shenzhen presented that the most abundant PAHs compound from Hunan and Cantonese cooking is pyrene. However, chrysene and triphenylene were the most abundant PAHs species from American cooking (Schauer et al., 1999, 2002).

Figure 4-1-11 shows the distributions of gaseous PAHs and particulate PAHs contained in total PAHs. For total PAHs, it is found that the fractions of gaseous PAHs in the six sampled restaurants ranged from 80% to 100%, which means that most PAHs were in gaseous phase in cooking fume exhaust. One study in Taiwan (Li et al., 2003) found that the range of the fractions of gaseous PAHs in four types of restaurant (Chinese, Western, Fast Food and Japanese) is 75.9% to 89.9%, which is a little bit lower than this study.

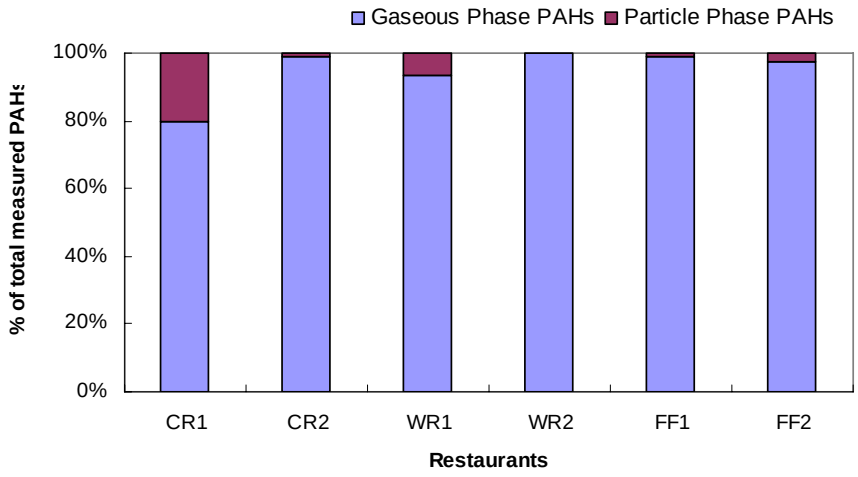


Figure 4-1-11 Distribution of gaseous PAHs and particulate PAHs contained in total PAHs for the six sampled restaurants

For gaseous phase PAHs, the distribution patterns of PAHs from two Chinese restaurants were similar. The most abundant PAHs compound is naphthalene, followed by acenaphthylene and phenanthrene. However, the PAHs emission patterns in western and fast food restaurants were different. Naphthalene, fluorene and phenanthrene were the three most abundant PAHs species. This is consistent with the finding in another study conducted in the U.S.A whose cooking style is charboiling (Schauer et al., 1999).

For particle phase PAHs, the most abundant PAHs compound from two Chinese restaurants is pyrene which is consistent with He et al., 2004. However, chrysene and triphenylene have the highest concentrations from American cooking emissions (Rogge et al., 1991; Schauer et al., 1999, 2002). The distribution of particle phase PAHs in the cooking exhaust was described in Figure 4-1-12. Four-ring PAHs along

with three-ring PAHs, account for nearly 60% of total measured particle phase PAHs while two-ring PAHs contributed much less. The results indicate that different cooking styles will lead to different PAH emission patterns.

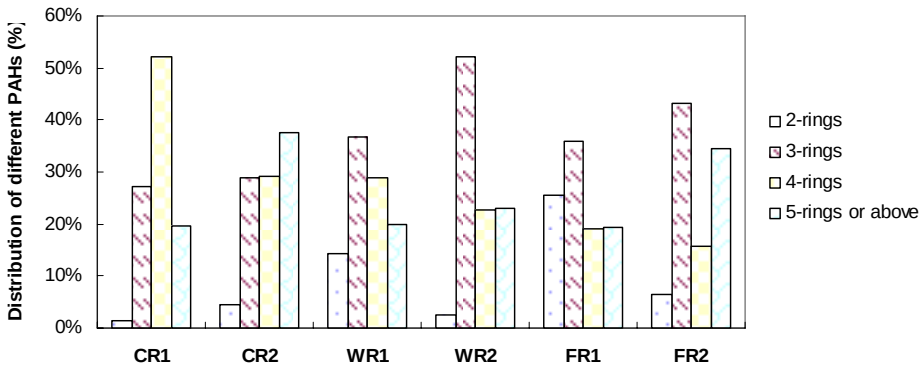
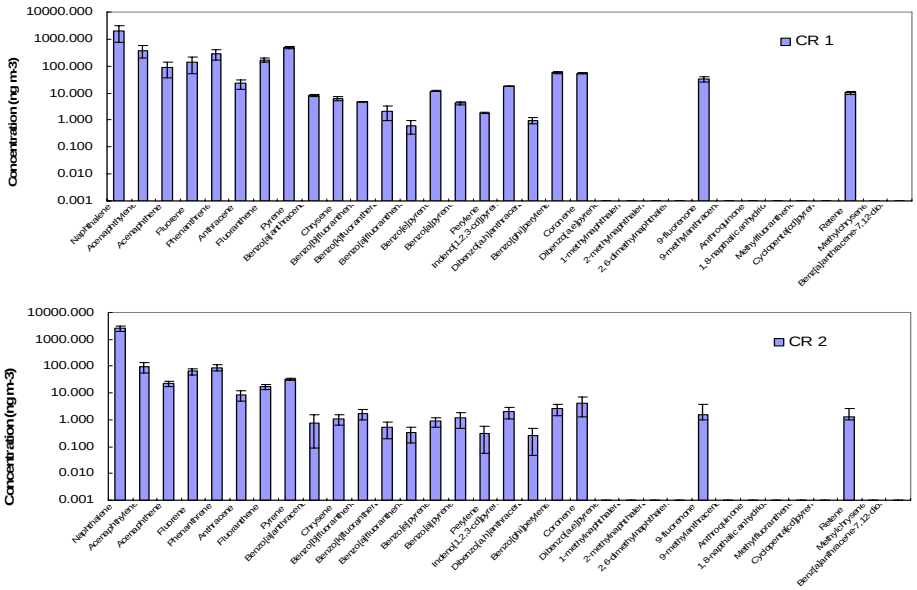
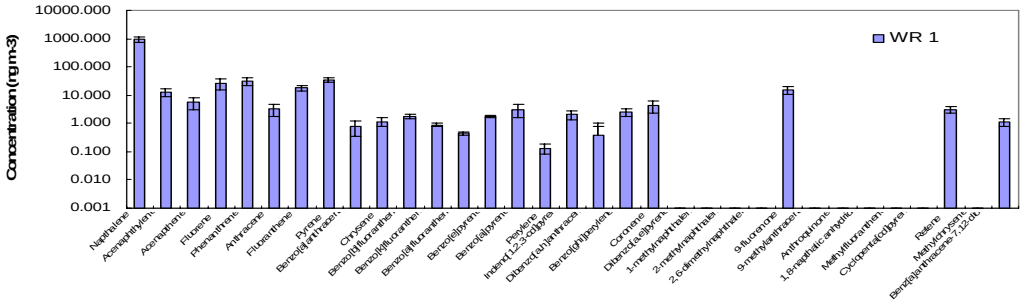


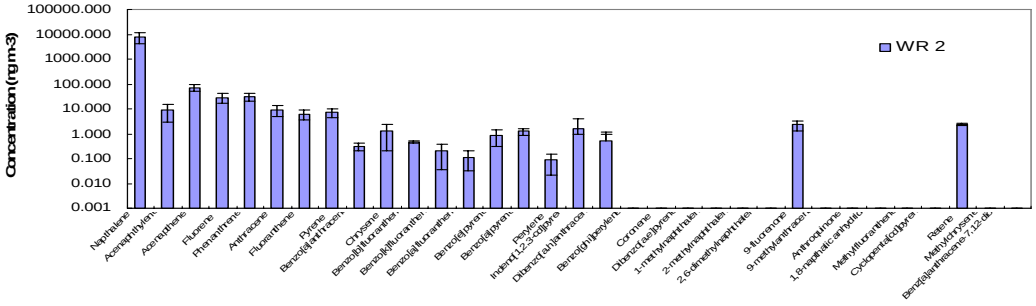
Figure 4-1-12 Distribution of 2-,3-,4-, and 5-rings or above particle phase PAHs in cooking fume exhaust in six sampled restaurants

The chemical profiles of total measured PAHs (gaseous + particle phase) at commercial restaurants are shown in Figure 4-1-13.


CR 1
Concentration (ng m-3)
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Naphthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo[a]anthracene
Chrysene
Benzo[b]fluoranthene
Benzo[k]fluoranthene
Benzo[j]fluoranthene
Benzo[e]pyrene
Benzo[a]pyrene
Perylene
Indeno[1,2,3-cd]pyrene
Dibenz[a,h]anthracene
Benzo[g,h,i]perylene
Coronene
Dibenz[a,e]pyrene
1-methylnaphthalene
2-methylnaphthalene
2,6-dimethylnaphthalene
9-fluorenone
9-methylanthracene
Anthraquinone
1,8-naphthalic anhydride
Methylfluoranthene
Cyclopenta[c,d]pyrene
Retene
Methylchrysene
Benzo[a]anthracene-7,12-dio

CR 2
Concentration (ng m-3)
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
Naphthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo[a]anthracene
Chrysene
Benzo[b]fluoranthene
Benzo[k]fluoranthene
Benzo[j]fluoranthene
Benzo[e]pyrene
Benzo[a]pyrene
Perylene
Indeno[1,2,3-cd]pyrene
Dibenz[a,h]anthracene
Benzo[g,h,i]perylene
Coronene
Dibenz[a,e]pyrene
1-methylnaphthalene
2-methylnaphthalene
2,6-dimethylnaphthalene
9-fluorenone
9-methylanthracene
Anthraquinone
1,8-naphthalic anhydride
Methylfluoranthene
Cyclopenta[c,d]pyrene
Retene
Methylchrysene
Benzo[a]anthracene-7,12-dio


Concentration (ng/m-3)
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
WR 1
Naphtalene
Acenaphthylen.
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo[a]anthracen.
Chrysene
Benzo[b]fluoranthen.
Benzo[k]fluoranthen.
Benzo[a]fluoranthen.
Benzo[e]pyren.
Benzo[a]pyren.
Perylene
Indeno[1,2,3-cd]pyren
Dibenz[a,h]anthracen
Benzo[ghi]perylen.
Coronene
Dibenz[a,e]pyren.
1-methylnaphthalin
2-methylnaphthalin
2,6-dimethylnaphthalin
9 fluorenone
9-methylanthracen.
Anthrachinone
1,8-naphtalic anhydrid.
Methylfluoranthen.
Cyclopenta[cd]pyre
Retene
Methylchrysen.
Benz[a]anthracene 7,12-dic.


Concentration (ng/m-3)
100000.000
10000.000
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
WR 2
Naphtalene
Acenaphthylen.
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo[a]anthracen.
Chrysene
Benzo[b]fluoranthen.
Benzo[k]fluoranthen.
Benzo[a]fluoranthen.
Benzo[e]pyren.
Benzo[a]pyren.
Perylene
Indeno[1,2,3-cd]pyren
Dibenz[a,h]anthracen
Benzo[ghi]perylen.
Coronene
Dibenz[a,e]pyren.
1-methylnaphthalin
2-methylnaphthalin
2,6-dimethylnaphthalin
9 fluorenone
9-methylanthracen.
Anthrachinone
1,8-naphtalic anhydrid.
Methylfluoranthen.
Cyclopenta[cd]pyre
Retene
Methylchrysen.
Benz[a]anthracene 7,12-dic.

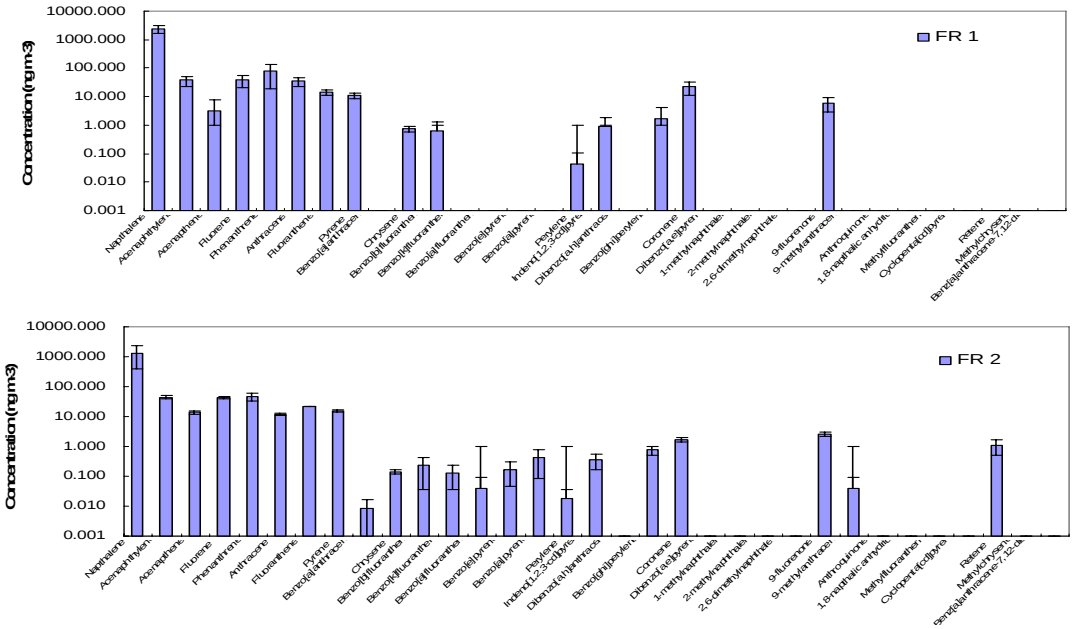


Figure 4-1-13 The mean chemical profile of total measured PAHs at commercial restaurants

Table 4-1-5 Average concentrations of PAHs (gaseous phase+ particulate phase; ng/m^3) in commercial restaurants

Site	CR 1		CR 2		WR 1		WR 2		FR 2		FR 1	
Gaseous PAHs	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Naphthalene	2020.84	1234.19	2497.08	582.14	970.97	220.11	7668.41	3568.08	1336.44	933.52	2415.54	752.13
Acenaphthylene	377.25	174.29	95.16	42.01	6.74	3.69	8.66	5.85	41.04	4.77	36.80	14.78
Acenaphthene	84.53	48.86	22.82	5.20	5.14	2.52	71.75	21.90	13.62	1.73	0.86	4.65
Fluorene	129.45	82.05	62.78	16.11	22.05	10.41	28.10	12.09	42.06	3.75	37.31	17.03
Phenanthrene	232.44	117.58	85.67	24.22	29.59	10.33	26.63	11.49	42.94	13.09	63.11	58.27
Anthracene	20.01	9.32	8.60	3.58	3.21	1.39	9.39	4.59	12.03	1.44	32.79	11.99
Fluoranthene	57.43	30.69	15.33	3.89	11.89	4.09	5.60	2.69	21.24	0.74	5.65	3.09
Pyrene	103.34	40.67	29.22	3.10	17.51	5.80	5.22	2.58	12.37	1.29	1.25	2.15
Total Measured G-PAHs	3025.29	1700.00	2816.66	630.00	1067.09	230.00	7823.77	360.00	1521.74	960.00	2593.32	740.00
Site	**CR 1**		**CR 2**		**WR 1**		**WR 2**		**FR 2**		**FR 1**	
Particle PAHs	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Napthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthylene	2.42	0.13	nd	nd	5.69	2.23	nd	nd	3.10	1.27	1.15	0.34
Acenapthene	1.24	0.10	nd	0.00	0.49	0.03	0.47	0.37	0.13	0.19	2.23	1.54
Fluorene	6.08	0.06	1.32	1.46	4.35	0.79	nd	nd	1.35	0.70	1.23	0.72
Phenanthrene	47.18	8.59	3.58	2.53	1.84	1.55	4.69	1.00	2.48	1.12	14.30	2.58
Anthracene	2.65	0.86	0.09	0.15	nd	nd	nd	0.17	nd	nd	1.21	0.51
Fluoranthene	109.82	15.66	2.13	2.43	6.68	1.22	0.61	0.49	0.41	0.32	8.73	0.88
Pyrene	368.04	62.22	4.29	3.49	16.06	2.50	1.91	0.71	2.85	0.72	9.72	1.43
Benzo[a]anthracene	8.05	0.59	0.78	0.69	0.77	0.43	0.31	0.10	0.01	0.01	nd	nd

Site	CR 1		CR 2		WR 1		WR 2		FR 2		FR 1	
Particle PAHs	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Chrysene	6.38	1.29	1.09	0.45	1.17	0.39	1.31	1.10	0.14	0.02	0.74	0.16
Benzo[b]fluoranthene	4.73	0.06	1.74	0.72	1.82	0.34	0.46	0.04	0.23	0.19	0.64	0.67
Benzo[k]fluoranthene	2.10	1.15	0.52	0.32	0.87	0.12	0.21	0.17	0.13	0.10	nd	nd
Benzo[a]fluoranthene	0.62	0.31	0.33	0.19	0.44	0.05	0.11	0.08	0.04	0.05	nd	nd
Benzo[e]pyrene	11.84	0.80	0.88	0.33	1.76	0.15	0.90	0.58	0.17	0.13	nd	nd
Benzo[a]pyrene	4.19	0.66	1.16	0.67	3.14	1.58	1.23	0.36	0.44	0.35	nd	nd
Perylene	1.85	0.09	0.32	0.26	0.13	0.05	0.09	0.07	0.02	0.02	0.04	0.06
Indeno[1,2,3-cd]pyrene	18.48	0.27	2.02	0.92	2.13	0.74	1.63	2.30	0.36	0.19	0.89	0.98
Dibenzo[a,h]anthracene	0.98	0.22	0.26	0.21	0.40	0.40	0.53	0.60	nd	nd	nd	nd
Benzo[ghi]perylene	56.26	5.12	2.55	1.15	2.51	0.80	nd	nd	0.75	0.25	1.62	2.43
Coronene	52.81	2.19	4.08	2.83	4.40	2.07	nd	nd	1.74	0.30	21.80	11.18
9-fluorenone	32.72	7.06	1.58	2.25	15.38	4.40	2.34	1.07	2.50	0.41	6.16	3.18
Retene	10.25	1.61	1.26	1.31	3.02	0.78	2.32	0.26	1.05	0.56	nd	nd
Total Measured P-PAHs	748.69	86.22	29.97	18.38	74.22	17.40	19.13	7.48	17.93	4.73	70.47	14.80

* S.D:Standard deviation
* CR: Chinese Restaurant; WR: Western Restaurant; FR: Fast Food Restaurant
* ND: Not Detectable

4.1.3.2 Fatty Acids

Fatty acids are emitted from many sources. The homologues <C20 are thought to be derived from meat cooking (Rogge et al., 1991), fossil fuel combustion (Simoneit., et a., 1985, 1986) and microbial sources, while the homologues >C22 are from vascular plant wax (Simoneit and Mazurek, 1982). The C_{16} and C_{18} fatty acids (both *n*-alkanoic acids and *n*-alkenoic acids) are among the most prominent single organic compounds found in the urban atmospheric fine particulate mixture. (Rogge et al., 1993).

Seed oil used for cooking and fat in meat contain large amounts of unsaturated and saturated fatty acid esters of glycerol. During the cooking process free fatty acids are liberated by hydrolysis and thermal oxidation of glycerides (Rogge et al., 1991). No free fatty acids were present in the refined seed oils used in the cooking experiments (Schauer et al., 2002). In this study, it is found that the organic compound emissions from all restaurants were dominated by fatty acids.

34 fatty acids (hexanoic acid, heptanoic acid, octanoic acid, nonanoic acid, decanoic acid, undenoic acid, dodecanoic acid, tridecanoic acid, tetradecanoic acid, pentadecanoic acid, hexadecanoic acid, octadecanoic acid, nonadecanoic acid, eicosanoic acid, heneicosanoic acid, docosanoic acid, tricosanoic acid, tetracosanoic acid, pentacosanoic acid, hexcosanoic acid, octacosanoic acid, nonacosanoic acid, triacontanoic acid, hentriacontanoic acid, dotriacontanoic acid, pinonic acid, palmitoleic acid, oleic acid, linoleic acid, linolenic acid pimaric acid and abietic acid were analyzed in this study.

On average, the mean concentrations of total measured fatty acids (sum of 34 species) for all restaurants were 64.16±45.24 μg m^{-3} (CR 1), 26.43±13.78 μg m^{-3} (CR 2), 27.47±0.34 μg m^{-3} (WR 1), 83.00±14.11 μg m^{-3} (WR 2), 97.00±19.46 μg

m^{-3} (FR 1) and 141.89 ± 27.49 μg m^{-3} (FR 2). Figure 4-1-10 shows the total measured fatty acids at all sampled restaurants. In terms of mass concentration levels and assigning the sites in descending order with site characteristics, it is observed that FR 2> FR 1> WR 2> CR 1> > WR 1 > CR 2. Generally speaking, fast food restaurants, whose main cooking style is deep frying, have the highest fatty acid emission.

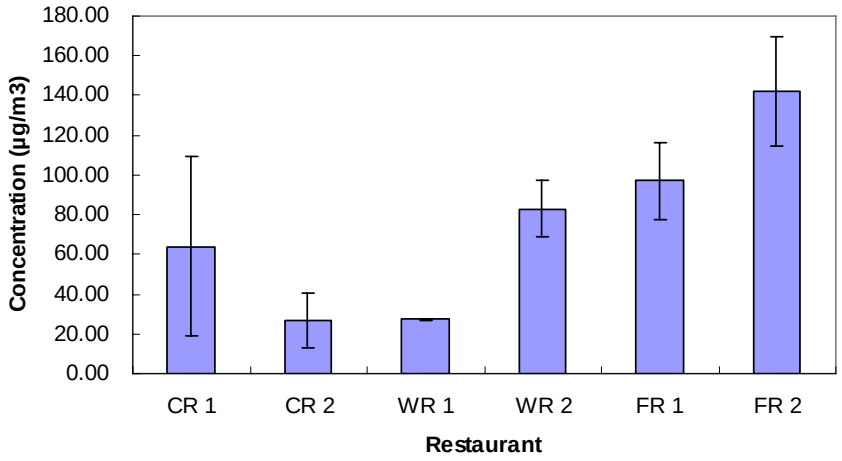


Figure 4-1-14 Mean concentrations of fatty acid in each restaurant

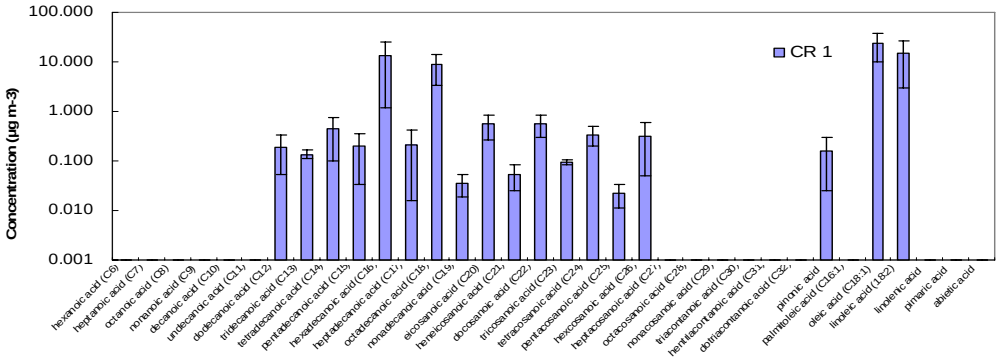
In the $PM_{2.5}$ samples of all restaurants, the n-alkanoic acid analogous showed a similar distribution pattern, with a strong even carbon number predominance and a carbon maximum at C16 followed by C18.

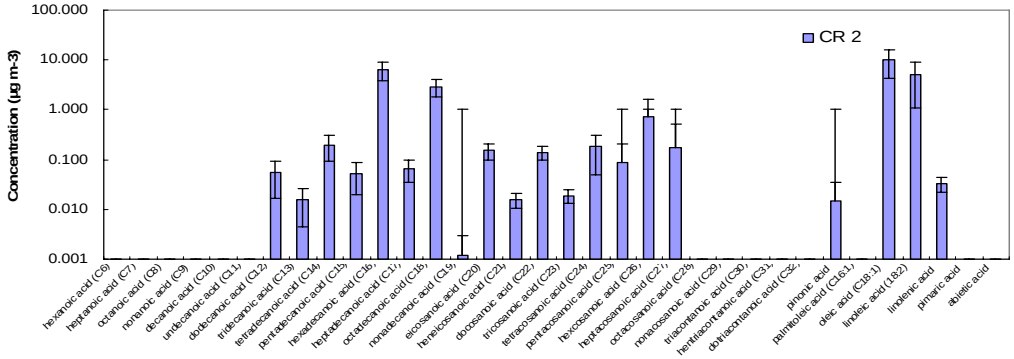
Besides the normal alkanoic acids, three alkenoic acids, i.e., oleic (C18:1), linoleic (C18:2), and palmtoleic (C16:1) acids, were also abundant among all fatty acids measured. This is consistent with the finds that cooking emissions is an important source for alkenoic acids, especially for oleic and palmitoleic acids (Rogge et al., 1991, Schauer et al., 1999, 2002, He et al., 2004). He (He et el., 2004) also found that in Chinese cooking, organic compounds was dominated by fatty acids

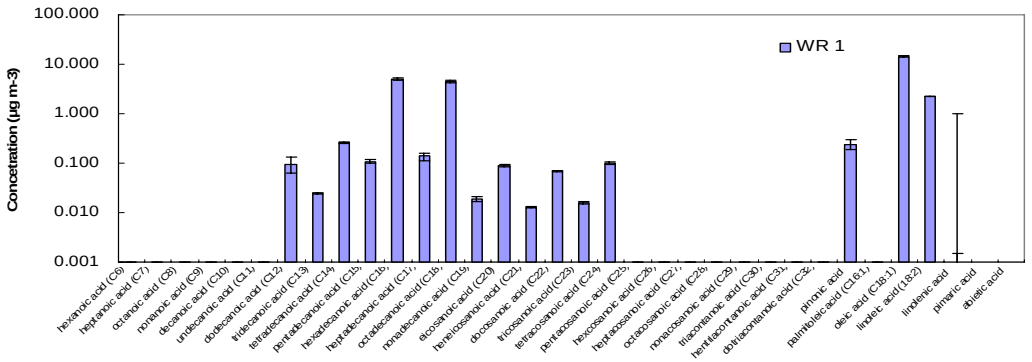
including a large amount of alkenoic acids.

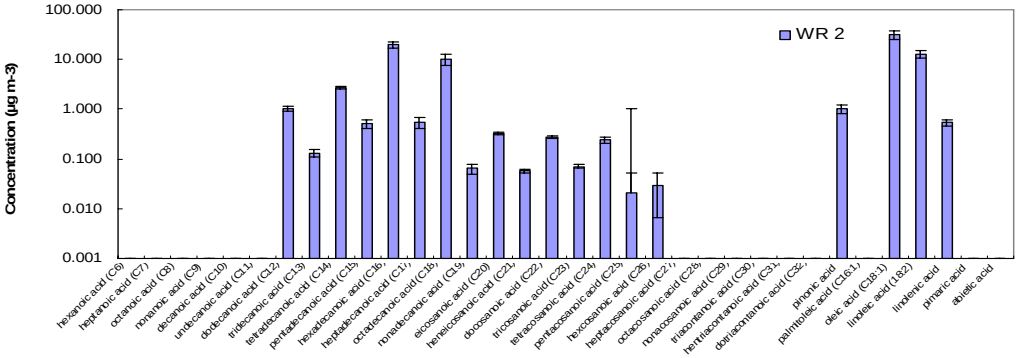
Vegetable oil is a type of common cooking oil used in restaurants in Hong Kong. Vegetable oils are derived from oil-bearing crops, such as soybeans, rapeseed, palm kernel, and olives (Morgan et al., 1993). Table 4-1-5 indicates the largest monounsaturated C18 acid (oleic acid, 9-octadecenoic acid) emissions were observed at nearly all sampling sites. This may attribute to the oil used during cooking operation. In canola oil, oleic acid (9-octadecenoic acid) makes up a higher fraction of the acids present as esters than in any other of commercial edible seed oil.

The chemical profiles of total measured fatty acids at commercial restaurants are shown in the following figures. Table 4-1-6 presents the concentrations of all fatty acids measured in this study.


100.000
10.000
1.000
0.100
0.010
0.001
Concentration (µg m-3)
CR 1
hexanoic acid (C6)
heptanoic acid (C7)
octanoic acid (C8)
nonanoic acid (C9)
decanoic acid (C10)
undecanoic acid (C11)
dodecanoic acid (C12)
tridecanoic acid (C13)
tetradecanoic acid (C14)
pentadecanoic acid (C15)
hexadecanoic acid (C16)
heptadecanoic acid (C17)
octadecanoic acid (C18)
nonadecanoic acid (C19)
eicosanoic acid (C20)
henelcosanoic acid (C21)
docosanoic acid (C22)
tricosanoic acid (C23)
tetracosanoic acid (C24)
pentacosanoic acid (C25)
hexacosanoic acid (C26)
heptacosanoic acid (C27)
octacosanoic acid (C28)
nonacosanoic acid (C29)
triacontanoic acid (C30)
hentriacontanoic acid (C31)
dotriacontanoic acid (C32)
pinonic acid
palmitoleic acid (C16:1)
oleic acid (C18:1)
linoleic acid (182)
linolenic acid
pimaric acid
abietic acid


100.000
10.000
1.000
0.100
0.010
0.001
Concentration (µg m-3)
CR 2
hexanoic acid (C6)
heptanoic acid (C7)
octanoic acid (C8)
nonanoic acid (C9)
decanoic acid (C10)
undecanoic acid (C11)
dodecanoic acid (C12)
tridecanoic acid (C13)
tetradecanoic acid (C14)
pentadecanoic acid (C15)
hexadecanoic acid (C16)
heptadecanoic acid (C17)
octadecanoic acid (C18)
nonadecanoic acid (C19)
eicosanoic acid (C20)
henelcosanoic acid (C21)
docosanoic acid (C22)
tricosanoic acid (C23)
tetracosanoic acid (C24)
pentacosanoic acid (C25)
hexacosanoic acid (C26)
heptacosanoic acid (C27)
octacosanoic acid (C28)
nonacosanoic acid (C29)
triacontanoic acid (C30)
hentriacontanoic acid (C31)
dotriacontanoic acid (C32)
pinonic acid
palmitoleic acid (C16:1)
oleic acid (C18:1)
linoleic acid (182)
linolenic acid
pimaric acid
abietic acid


Concetration (µg m-3)
100.000
10.000
1.000
0.100
0.010
0.001
WR 1
hexanoic acid (C6)
heptanoic acid (C7)
octanoic acid (C8)
nonanoic acid (C9)
decanoic acid (C10)
undecanoic acid (C11)
dodecanoic acid (C12)
tridecanoic acid (C13)
tetradecanoic acid (C14)
pentadecanoic acid (C15)
hexadecanoic acid(C16)
heptadecanoic acid (C17)
octadecanoic acid(C18)
nonadecanoic acid (C19)
eicosanoic acid (C20)
heneicosanoic acid (C21)
docosanoic acid (C22)
tricosanoic acid(C23)
tetracosanoic acid (C24)
pentacosanoic acid (C25)
hexacosanoic acid (C26)
heptacosanoic acid (C27)
octacosanoic acid (C28)
nonacosanoic acid (C29)
triacontanoic acid(C30)
hentriacontanoic acid (C31)
dotriacontanoic acid (C32)
pimaric acid
palmitoleic acid (C16:1)
oleic acid (C18:1)
linoleic acid (18:2)
linolenic acid
pimaric acid
abietic acid


Concentration (µg m-3)
100.000
10.000
1.000
0.100
0.010
0.001
WR 2
hexanoic acid (C6)
heptanoic acid (C7)
octanoic acid (C8)
nonanoic acid (C9)
decanoic acid (C10)
undecanoic acid (C11)
dodecanoic acid (C12)
tridecanoic acid (C13)
tetradecanoic acid (C14)
pentadecanoic acid (C15)
hexadecanoic acid (C16)
heptadecanoic acid (C17)
octadecanoic acid(C18)
nonadecanoic acid (C19)
eicosanoic acid (C20)
heneicosanoic acid (C21)
docosanoic acid (C22)
tricosanoic acid(C23)
tetracosanoic acid (C24)
pentacosanoic acid (C25)
hexacosanoic acid (C26)
heptacosanoic acid (C27)
octacosanoic acid (C28)
nonacosanoic acid (C29)
triacontanoic acid(C30)
hentriacontanoic acid (C31)
dotriacontanoic acid (C32)
pimaric acid
palmitoleic acid (C16:1)
oleic acid (C18:1)
linoleic acid (18:2)
linolenic acid
pimaric acid
abietic acid

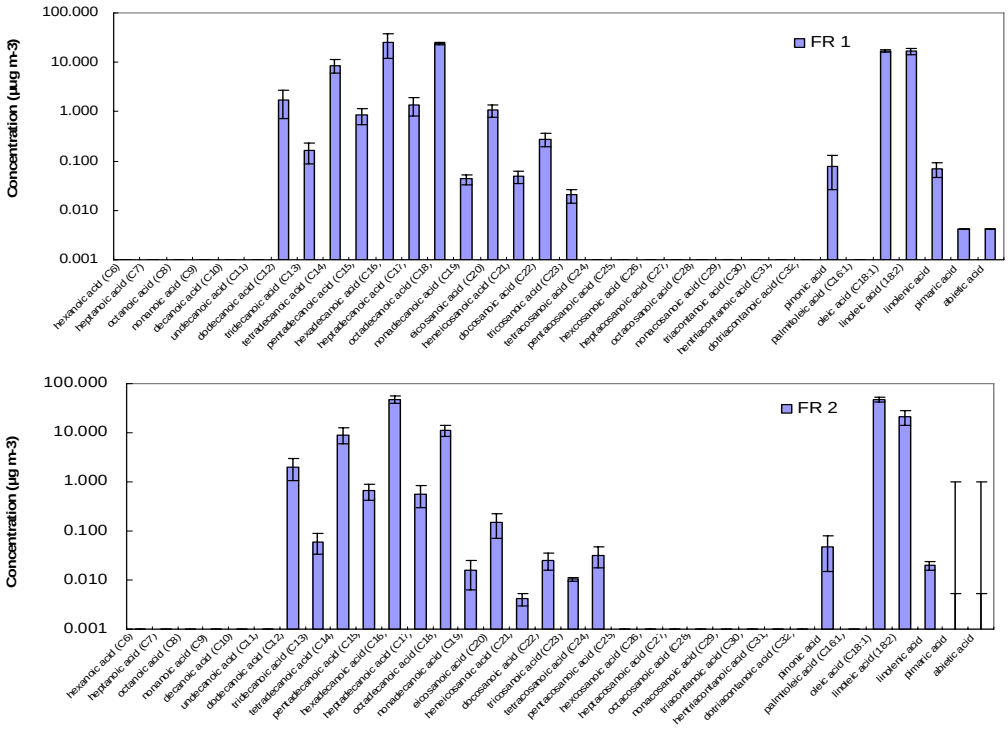


Figure 4-1-15 The mean chemical profile of total measured fatty acids at commercial restaurants

Table 4-1-6 Average concentration of fatty acids in commercial restaurants

Site	CR 1 (μgm^{-3})			CR 2 (μgm^{-3})			WR 1 (μgm^{-3}))			WR 2 (μgm^{-3})			FR 2 (μgm^{-3})			FR 1 (μgm^{-3})		
Fatty Acids	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
hexanoic acid (C6)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
heptanoic acid (C7)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
octanoic acid (C8)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
nonanoic acid (C9)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
decanoic acid (C10)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
undecanoic acid (C11)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
dodecanoic acid (C12)	0.19	4	0.14	0.05	5	0.04	0.10	5	0.03	1.02	7	0.12	1.99	6	0.96	1.74	5	1.02
tridecanoic acid (C13)	0.14	4	0.03	0.02	5	0.01	0.02	5	0.00	0.13	7	0.02	0.06	6	0.03	0.16	5	0.07
tetradecanoic acid (C14)	0.43	4	0.33	0.20	5	0.10	0.26	5	0.01	2.74	7	0.16	9.16	6	3.09	8.68	5	2.78
pentadecanoic acid (C15)	0.19	4	0.16	0.05	5	0.03	0.11	5	0.01	0.51	7	0.10	0.65	6	0.23	0.85	5	0.29
hexadecanoic acid (C16)	13.18	4	11.97	6.45	5	2.61	5.09	5	0.29	20.17	7	3.01	47.87	6	7.57	25.07	5	13.37
heptadecanoic acid (C17)	0.22	4	0.20	0.07	5	0.03	0.14	5	0.02	0.55	7	0.14	0.58	6	0.28	1.35	5	0.52
octadecanoic acid (C18)	8.72	4	5.47	2.92	5	1.06	4.55	5	0.28	10.17	7	2.58	11.42	6	2.88	23.75	5	1.73
nonadecanoic acid (C19)	0.04	4	0.02	0.00	5	0.00	0.02	5	0.00	0.06	7	0.01	0.02	6	0.01	0.04	5	0.01
eicosanoic acid (C20)	0.56	4	0.29	0.15	5	0.05	0.09	5	0.01	0.33	7	0.02	0.15	6	0.08	1.08	5	0.30
heneicosanoic acid (C21)	0.05	4	0.03	0.02	5	0.00	0.01	5	0.00	0.06	7	0.01	0.00	6	0.00	0.05	5	0.01
docosanoic acid (C22)	0.57	4	0.28	0.14	5	0.05	0.07	5	0.00	0.28	7	0.02	0.03	6	0.01	0.27	5	0.08
tricosanoic acid (C23)	0.10	4	0.01	0.02	5	0.01	0.02	5	0.00	0.07	7	0.01	0.01	6	0.00	0.02	5	0.01
tetracosanoic acid (C24)	0.34	4	0.15	0.18	5	0.13	0.10	5	0.00	0.24	7	0.03	0.03	6	0.01	0.00	5	0.00
pentacosanoic acid (C25)	0.02	4	0.01	0.09	5	0.11	0.00	5	0.00	0.02	7	0.03	0.00	6	0.00	0.00	5	0.00
hexcosanoic acid (C26)	0.32	4	0.27	0.71	5	0.92	0.00	5	0.00	0.03	7	0.02	0.00	6	0.00	0.00	5	0.00

Site	CR 1 (μgm^{-3})			CR 2 (μgm^{-3})			WR 1 (μgm^{-3}))			WR 2 (μgm^{-3})			FR 2 (μgm^{-3})			FR 1 (μgm^{-3})		
Fatty Acids	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
heptacosanoic acid (C27)	0.00	4	0.00	0.17	5	0.35	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
octacosanoic acid (C28)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
nonacosanoic acid (C29)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
triacontanoic acid (C30)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
hentriacontanoic acid (C31)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
dotriacontanoic acid (C32)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
pinonic acid	0.16	4	0.13	0.01	5	0.02	0.24	5	0.05	1.01	7	0.21	0.05	6	0.03	0.08	5	0.05
palmitoleic acid (C16:1)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
oleic acid (C18:1)	23.79	4	13.66	10.01	5	5.82	14.38	5	0.61	32.21	7	6.39	48.52	6	5.85	16.96	5	1.28
linoleic acid (18:2)	15.15	4	12.18	5.14	5	4.05	2.27	5	0.00	12.86	7	1.91	21.34	6	7.50	16.81	5	2.31
linolenic acid	0.00	4	0.00	0.03	5	0.01	0.00	5	0.00	0.54	7	0.07	0.02	6	0.00	0.07	5	0.02
pimaric acid	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
abietic acid	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	6	0.00	0.00	5	0.00
Total Measured Fatty Acid	64.16	4	45.24	26.43	5	13.78	27.47	5	0.34	83.00	7	14.11	141.89	6	27.49	97.00	5	19.46

* S.D: standard deviation
* CR: Chinese Restaurant; WR: Western Restaurant; FR: Fast Food Restaurant
* N: Number of samples
* nd: not detected

4.1.3.3 Alkane

There are many sources of n-alkanes, including both anthropogenic and borgenic sources, and the relative distribution of n-alkane homologues can indicate different sources (Rogge et al., 1993).

Under ambient conditions, the normal alkanes with carbon numbers C_{21} and higher are found mainly in the particular phase due to their low vapor pressure. In this study, 24 gas phase alkanes from C_{11} to C_{34} and 34 particle phase alkanes from C_{15} to C_{33} were identified and quantified in the cooking fume.

On average, the mean concentrations of total measured gas phase alkane (sum of 24 species) for all restaurants were 0.67±0.47 μg m^{-3} (CR 1), 1.97±0.44 μg m^{-3} (CR 2), 0.59±0.31 μg m^{-3} (WR 1), 4.76±0.82 μg m^{-3} (WR 2), 2.56±0.81 μg m^{-3} (FR 1) and 1.16±0.30 μg m^{-3} (FR 2) and. On the other side, the mean concentrations of total measured particle phase alkane (sum of 34 species) for all restaurants were 1.13± 0.22 μg m^{-3} (CR 1), 0.29±0.11 μg m^{-3} (CR 2), 1.01±0.08 μg m^{-3} (WR 1), 0.73±0.15 μg m^{-3} (WR 2), 1.07±0.46 μg m^{-3} (FR 1) and 0.24±0.03 μg m^{-3} (FR 2). Figure 4-1-16 shows the gas and particle partitioning of alkane at all sampled restaurants. From this figure, it can be seen that most alkane are presented in gaseous phase in all sampled restaurants except CR 1 and WR 1.

Comment: Change Restaurant name

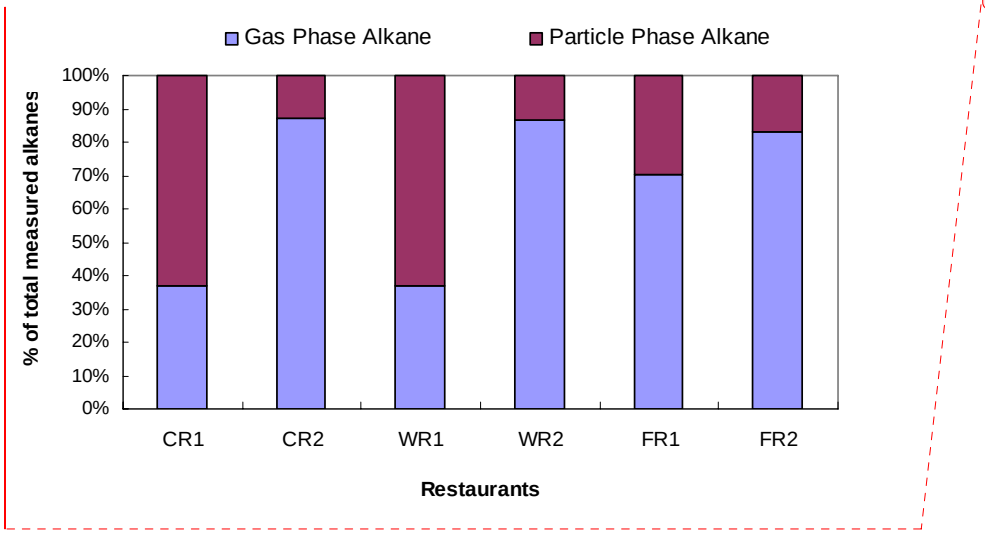


Figure 4-1-16 Distribution of gaseous alkanes and particulate alkanes contained in total alkanes for the six sampled restaurants

The particle phase alkane distribution diagrams for six sampled restaurants are shown in figure 4-1-17.

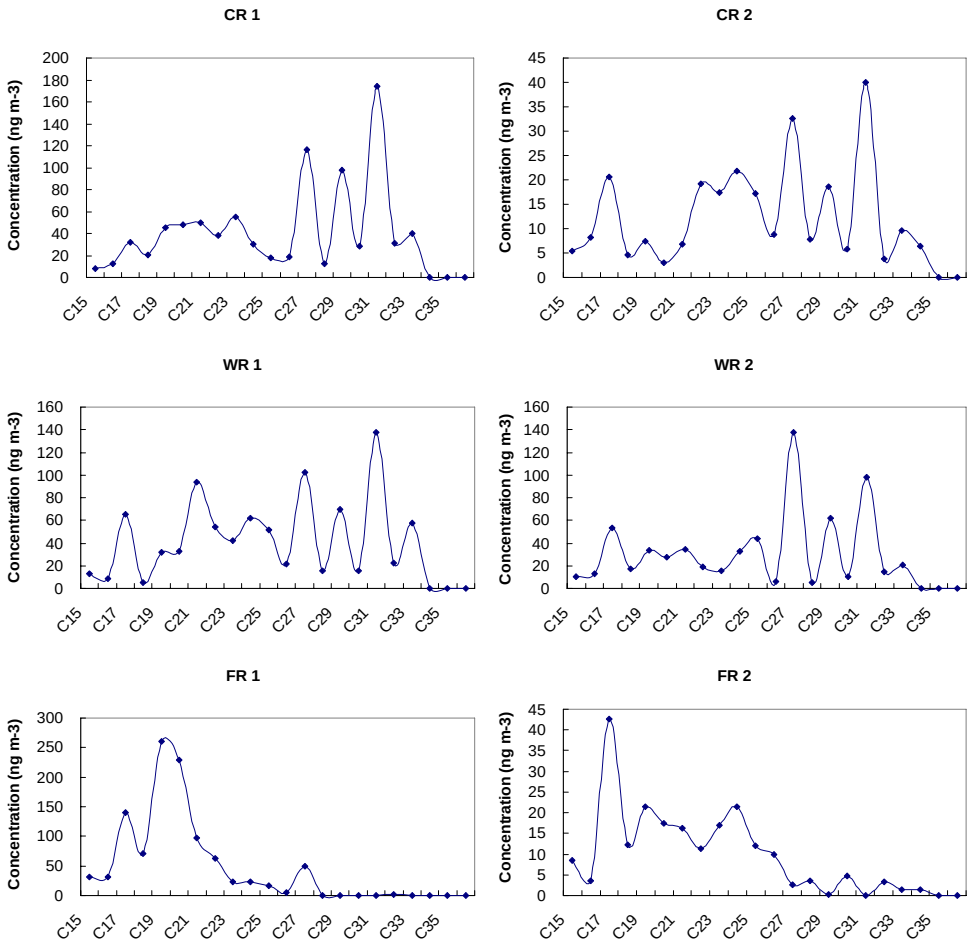


Figure 4-1-17 Alkane distribution diagrams for six sampled restaurants

The alkane distribution diagrams for restaurants were different from that of ambient and vehicle. The distribution analogous of diesel comprises of n-alkanes in a carbon number range of C18 to C26, with no carbon number predominance and maximum at C_{22} to C_{23} (Simoneit, 1984, 1985; Standley, 1988). A study conducted in Hong Kong (Zheng et al., 2000) found that all ambient air samples had a Cmax of C_{31}

and C_{29}, with no maximum at C_{14} to C_{20}. These differences indicate that cooking is a unique source of alkane. However, the distributions of n-alkanes emitted from the two Chinese restaurants in this study were substantially different from the alkane patterns from Chinese restaurants in Shenzhen (He et al., 2004).

From the figures above, it can be seen that alkane distribution patterns for different types of restaurants were different. In both Chinese and western restaurants, the samples had a Cmax of C_{27}, C_{29} or C_{31}. In both fast food restaurants, however, C_{27}, C_{29} and C_{31} all had very low concentrations. The difference may attribute to the cooking style, as deep frying is the main cooking style in both fast food restaurants.

CPI (Carbon Preference Index) is an index which can be used to identify the distribution of recent biogenic organic matter and anthropogenic materials (Simoneit, 1986). The CPIs of the alkanes in our samples were shown in table 4-1-7.

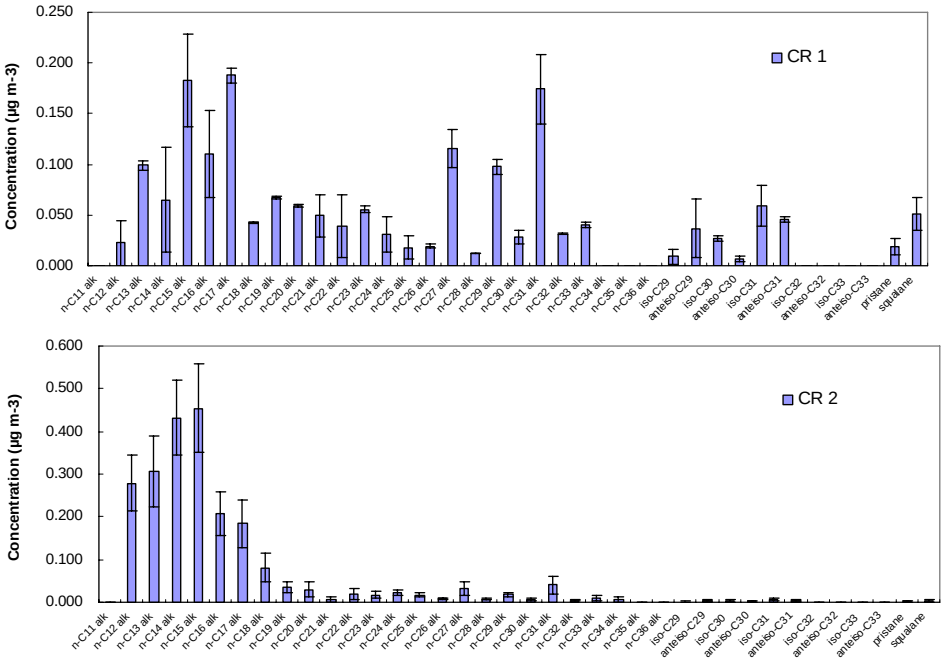
Table 4-1-7 Total particle phase alkanes concentrations and index

Restaurants	Total Particle Phase Alkanes (ng m^{-3})	CPI[a]	Cmax[b]
CR 1	1132.42±216.45	2.63	C_{31}
CR 2	291.62±112.36	1.97	C_{31}
WR 1	1007.36±82.16	2.8	C_{31}
WR 2	726.55±153.58	3.49	C_{27}
FR 1	1072.10±460.61	1.46	C_{19}
FR 2	239.89±57.06	1.38	C_{17}

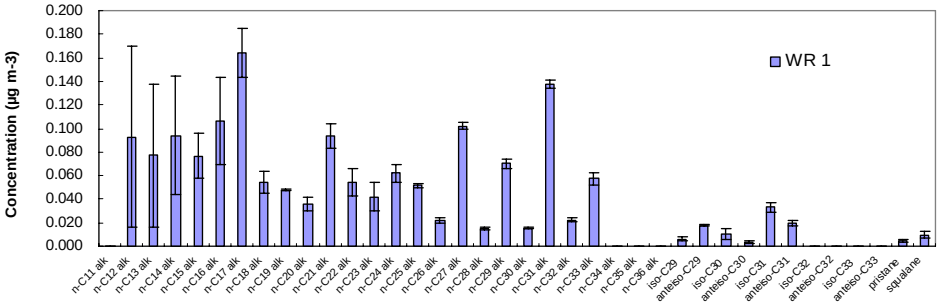
[a]CPI: Carbon Preference Index: odd-to-even for n-alkane
[b]Cmax: carbon number maximum, the carbon number with the highest concentration in that fraction

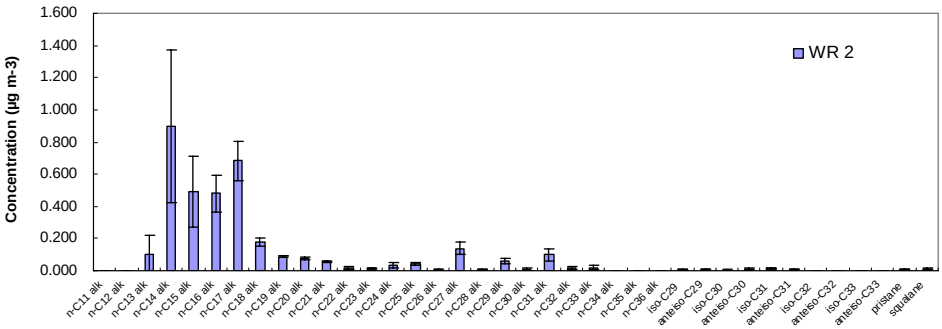
The CPI of the alkanes in all restaurant samples ranges from 1.38 to 2.63. Fast food restaurants had relatively low CPI when compared to Chinese restaurant and western restaurant. CPI is an effective index in the source apportionment of aerosol and low CPI is indication of high contribution from petroleum residues. These high CPIs measured in this study may attribute to these organic matters.

The chemical profiles of total measured alkanes (gas phase+ particle phase) at commercial restaurants are shown in figure 4-1-18. Table 4-1-8 presents the concentrations of all alkanes measured in this study.


Concentration (µg m-3)
0.250
0.200
0.150
0.100
0.050
0.000
CR 1
n-C11 alk
n-C12 alk
n-C13 alk
n-C14 alk
n-C15 alk
n-C16 alk
n-C17 alk
n-C18 alk
n-C19 alk
n-C20 alk
n-C21 alk
n-C22 alk
n-C23 alk
n-C24 alk
n-C25 alk
n-C26 alk
n-C27 alk
n-C28 alk
n-C29 alk
n-C30 alk
n-C31 alk
n-C32 alk
n-C33 alk
n-C34 alk
n-C35 alk
n-C36 alk
iso-C29
anteiso-C29
iso-C30
anteiso-C30
iso-C31
anteiso-C31
iso-C32
anteiso-C32
iso-C33
anteiso-C33
pristane
squalane

Concentration (µg m-3)
0.600
0.500
0.400
0.300
0.200
0.100
0.000
CR 2
n-C11 alk
n-C12 alk
n-C13 alk
n-C14 alk
n-C15 alk
n-C16 alk
n-C17 alk
n-C18 alk
n-C19 alk
n-C20 alk
n-C21 alk
n-C22 alk
n-C23 alk
n-C24 alk
n-C25 alk
n-C26 alk
n-C27 alk
n-C28 alk
n-C29 alk
n-C30 alk
n-C31 alk
n-C32 alk
n-C33 alk
n-C34 alk
n-C35 alk
n-C36 alk
iso-C29
anteiso-C29
iso-C30
anteiso-C30
iso-C31
anteiso-C31
iso-C32
anteiso-C32
iso-C33
anteiso-C33
pristane
squalane


Concentration (µg m-3)
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
WR 1
n-C11 alk
n-C12 alk
n-C13 alk
n-C14 alk
n-C15 alk
n-C16 alk
n-C17 alk
n-C18 alk
n-C19 alk
n-C20 alk
n-C21 alk
n-C22 alk
n-C23 alk
n-C24 alk
n-C25 alk
n-C26 alk
n-C27 alk
n-C28 alk
n-C29 alk
n-C30 alk
n-C31 alk
n-C32 alk
n-C33 alk
n-C34 alk
n-C35 alk
n-C36 alk
iso-C29
anteiso-C29
iso-C30
anteiso-C30
iso-C31
anteiso-C31
iso-C32
anteiso-C32
iso-C33
anteiso-C33
prisitane
squalane


Concentration (µg m-3)
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
WR 2
n-C11 alk
n-C12 alk
n-C13 alk
n-C14 alk
n-C15 alk
n-C16 alk
n-C17 alk
n-C18 alk
n-C19 alk
n-C20 alk
n-C21 alk
n-C22 alk
n-C23 alk
n-C24 alk
n-C25 alk
n-C26 alk
n-C27 alk
n-C28 alk
n-C29 alk
n-C30 alk
n-C31 alk
n-C32 alk
n-C33 alk
n-C34 alk
n-C35 alk
n-C36 alk
iso-C29
anteiso-C29
iso-C30
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anteiso-C32
iso-C33
anteiso-C33
prisitane
squalane

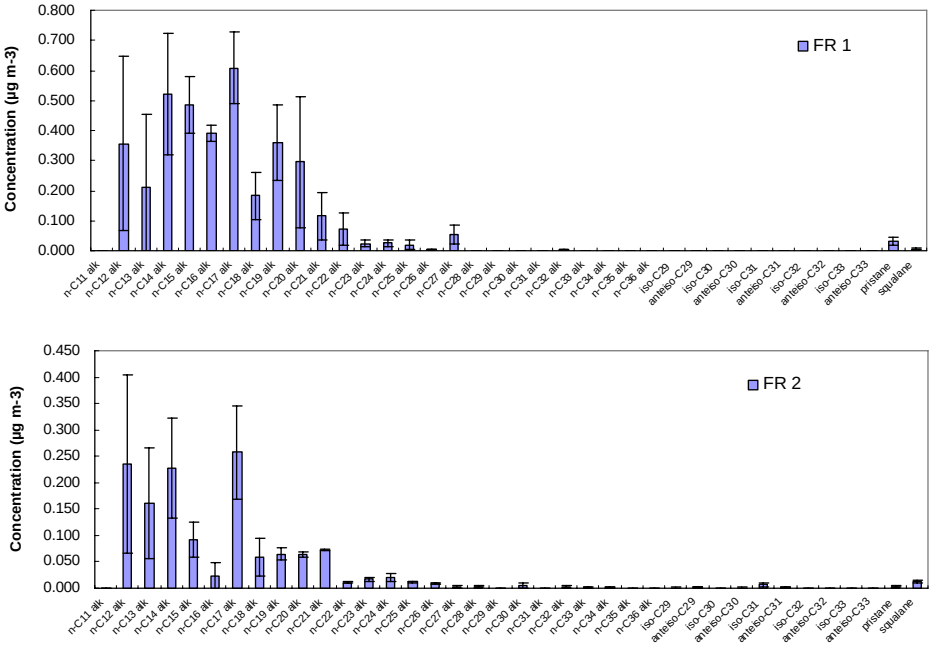


Figure 4-1-18 The mean chemical profile of total measured alkanes at commercial restaurants

Table 4-1-8 Average concentrations of n-alkanes (gaseous phase+ particulate phase; ng/m^3) in commercial restaurants

Site	CR 1 (ngm^{-3})			CR 2 (ngm^{-3})			WR 1 (ngm^{-3})			WR 2 (ngm^{-3})			FR 1 (ngm^{-3})			FR 2 (ngm^{-3})		
Gaseous Alkane	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
n-undecane (C-11)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-dodecane (C-12)	22.37	4	38.74	278.27	5	65.98	92.90	5	80.24	473.24	7	0.00	356.41	5	289.58	206.61	6	192.39
n-tridecane (C-13)	98.83	4	52.31	305.00	5	83.05	77.23	5	65.28	1408.37	7	227.57	213.11	5	239.39	141.53	6	121.30
n-tetradecane (C-14)	64.78	4	97.39	432.18	5	87.87	93.98	5	51.37	1595.10	7	465.66	521.32	5	201.78	254.62	6	138.06
n-pentadecane (C-15)	174.72	4	104.15	449.79	5	104.07	64.15	5	33.09	639.42	7	199.71	450.61	5	93.05	88.34	6	64.96
n-hexadecane (C-16)	97.54	4	82.05	198.78	5	48.56	98.02	5	41.11	427.51	7	111.86	361.54	5	24.61	22.62	6	27.93
n-heptadecane (C-17)	155.69	4	50.81	167.50	5	47.67	98.68	5	39.99	537.97	7	105.31	468.54	5	55.13	241.44	6	109.23
n-octadecane (C-18)	21.83	4	30.43	76.69	5	32.36	49.03	5	16.93	147.34	7	20.98	102.51	5	13.11	55.73	6	34.42
n-nonadecane (C-19)	21.30	4	14.34	29.77	5	11.66	15.70	5	4.82	49.22	7	7.93	40.25	5	10.17	46.14	6	13.69
n-eicosane (C-20)	10.37	4	11.42	27.82	5	16.03	2.81	5	4.86	37.86	7	16.05	23.06	5	15.91	48.15	6	12.20
n-henicosane (C-21)	nd	4	nd	nd	5	nd	nd	5	nd	19.54	7	7.35	18.65	5	2.01	56.44	6	5.76
n-docosane (C-22)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-tricosane (C-23)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-tetracosane (C-24)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-pentacosane (C-25)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-hexacosane (C-26)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-heptacosane (C-27)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-octacosane (C-28)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-nonacosane (C-29)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-triacontane (C-30)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-hentriacontane (C-31)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-dotriacontane (C-32)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-tritriacontane (C-33)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-tetratriacontane (C-34)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
Total Gaseous Alkane	667	4	470	1965.81	5	440	592.50	5	310	5335.57	7	820	2555.98	5	810	1161.62	6	300

Site	CR 1 (ngm^{-3})			CR 2 (ngm^{-3})			WR 1 (ngm^{-3})			WR 2 (ngm^{-3})			FR 1 (ngm^{-3})			FR 2 (ngm^{-3})		
Particle Alkane	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
n-C15 alk	8.31	4	5.07	5.49	5	3.64	12.48	5	11.23	10.56	7	4.89	30.70	5	19.26	8.43	6	3.53
n-C16 alk	12.47	4	2.46	8.11	5	7.08	8.23	5	0.78	12.91	7	10.03	30.85	5	7.32	3.48	6	0.86
n-C17 alk	32.02	4	13.38	20.69	5	13.52	65.52	5	13.91	53.32	7	7.63	140.31	5	108.57	42.58	6	28.31
n-C18 alk	20.84	4	16.00	4.60	5	4.09	5.22	5	1.65	17.18	7	2.60	70.43	5	63.43	12.18	6	2.19
n-C19 alk	45.46	4	7.07	7.33	5	5.63	32.24	5	4.32	33.77	7	14.35	260.97	5	164.52	21.40	6	4.86
n-C20 alk	48.34	4	8.63	3.04	5	3.13	32.98	5	8.49	27.72	7	1.91	229.81	5	213.00	17.46	6	8.69
n-C21 alk	49.37	4	20.98	6.71	5	7.18	93.46	5	10.25	34.08	7	5.51	96.58	5	71.77	16.33	6	2.67
n-C22 alk	38.36	4	30.95	19.14	5	11.20	54.11	5	11.71	18.81	7	6.53	63.28	5	56.97	11.28	6	2.06
n-C23 alk	55.47	4	3.22	17.47	5	7.96	42.17	5	12.33	15.17	7	4.62	22.45	5	12.11	16.90	6	4.00
n-C24 alk	30.57	4	17.38	21.70	5	5.93	62.12	5	7.66	32.51	7	15.14	22.44	5	11.87	21.34	6	7.97
n-C25 alk	17.75	4	11.45	17.17	5	4.39	51.58	5	1.57	43.58	7	6.22	17.23	5	18.13	11.93	6	2.08
n-C26 alk	19.04	4	2.14	8.75	5	1.84	21.66	5	2.48	5.79	7	2.55	4.25	5	1.88	9.81	6	1.37
n-C27 alk	116.10	4	18.95	32.66	5	16.67	102.17	5	2.90	137.24	7	37.94	49.10	5	35.60	2.58	6	2.82
n-C28 alk	12.14	4	0.06	7.76	5	1.70	15.28	5	0.90	5.39	7	1.71	nd	5	nd	3.59	6	1.35
n-C29 alk	97.86	4	7.33	18.56	5	5.30	69.98	5	3.93	62.17	7	18.00	nd	5	nd	0.20	6	0.28
n-C30 alk	28.32	4	7.10	5.85	5	2.98	15.50	5	0.99	10.67	7	9.12	nd	5	nd	4.66	6	5.36
n-C31 alk	174.06	4	33.98	40.07	5	21.74	137.51	5	3.13	97.71	7	34.77	nd	5	nd	nd	6	nd
n-C32 alk	31.47	4	0.84	3.77	5	1.20	22.30	5	1.55	14.47	7	9.96	2.18	5	2.81	3.20	6	2.04
n-C33 alk	39.94	4	2.88	9.64	5	6.31	57.61	5	5.12	20.58	7	15.34	nd	5	nd	1.35	6	1.00
n-C34 alk	nd	4	nd	6.31	5	6.43	nd	5	nd	nd	7	nd	nd	5	nd	1.37	6	0.97
n-C35 alk	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
n-C36 alk	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd

Site	CR 1 (ngm^{-3})			CR 2 (ngm^{-3})			WR 1 (ngm^{-3})			WR 2 (ngm^{-3})			FR 1 (ngm^{-3})			FR 2 (ngm^{-3})		
Particle Alkane	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
iso-C29	8.85	4	6.95	1.33	5	1.22	6.31	5	1.32	6.64	7	5.48	0.40	5	0.47	1.05	6	0.46
anteiso-C29	36.95	4	29.33	4.50	5	2.16	17.76	5	0.84	8.89	7	2.25	nd	5	nd	1.99	6	0.57
iso-C30	26.74	4	3.14	3.17	5	2.37	10.54	5	4.69	3.12	7	2.82	0.05	5	0.11	0.98	6	0.15
anteiso-C30	6.32	4	2.88	2.42	5	1.83	3.54	5	0.92	11.52	7	4.65	1.38	5	0.90	1.04	6	0.42
iso-C31	59.63	4	20.20	5.87	5	3.42	33.16	5	3.87	13.53	7	1.84	nd	5	nd	6.72	6	3.23
anteiso-C31	45.60	4	2.60	3.47	5	1.71	19.48	5	2.15	9.29	7	1.62	nd	5	nd	2.35	6	1.21
iso-C32	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
anteiso-C32	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
iso-C33	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
anteiso-C33	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
pristane	19.21	4	8.29	1.91	5	2.13	4.90	5	1.23	7.34	7	0.89	24.73	5	18.02	2.94	6	1.49
squalane	51.19	4	16.35	4.11	5	2.84	9.53	5	2.90	12.57	7	5.32	4.96	5	3.06	12.73	6	3.21
Total Particle Phase Alkane	1132.42	4	216.45	291.62	5	112.36	1007.36	5	82.16	726.55	7	153.58	1072.10	5	460.61	239.89	6	57.06

* S.D: standard deviation
* CR: Chinese Restaurant; WR: Western Restaurant; FR: Fast Food
* N: Number of samples
* nd: not detected

4.1.3.4 Other Organic Compounds

Except PAHs, fatty acid and alkanes, other organic compounds were also found in the cooking fume. For example, **dicarbonxylic acid**, including oxalic, propanedioic, butanedioic, pentanedioic, hexanedioic, heptanedioic, octanedioic, nonanedioic, decanedioic, undecanedioic, dodecanedioic, tridecanedioic, tetradecanedioic, phthalic acid(1,2), isophthalic acid (1,3) and terephthalic acid (1,4); **alcohols**, including 1-undecanol, 1-dodecanol, 1-tridecanol, 1-tetradecanol, 1-pentadecanol, 1-hexadecanol, 1-heptadecanol, 1-octadecanol, 1-nonadecanol, 1-icosanol, 1-heneicosanol, 1-docosanol, 1-tricosanol, 1-docosanol, 1-pentacosanol, 1-hexacosanol, 1-heptacosanol, 1-octacosanol, 1-nonacosanol, 1-triacontanol, 1-hentriacontanol and 1-dotriacontanol; **carbonyls**, including methylglyoxal, glyoxylic acid, 3-oxo-propanoic acid, 4-oxo-butanoic acid, pyruvic and nonalal; and also **some other species**, for example, glycerine, levoglucosan, monopalmitin, monoolein, monostearin, cholesterol, ergosterol, stigmasterol and b-stisterol.

Figure 4-1-19 and figure 4-1-20 show the total gas phase and particle phase organic compounds emitted from commercial restaurants.

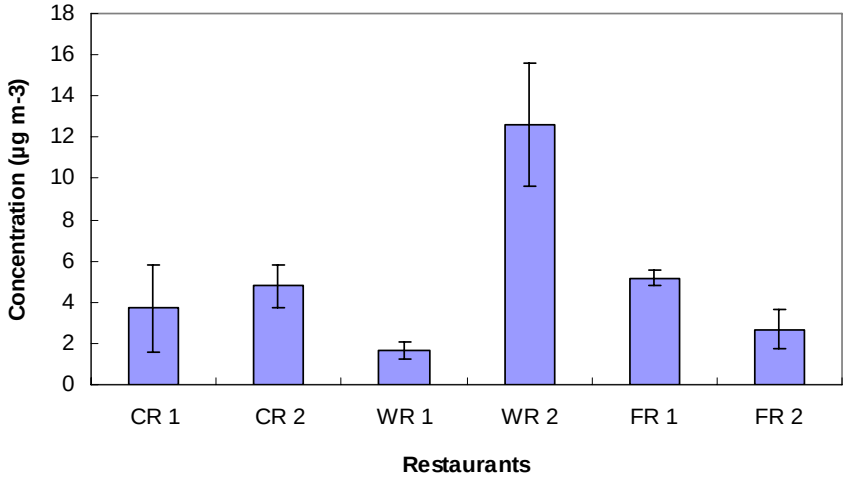


Figure 4-1-19 Mean concentrations of total gas phase organic compounds in each restaurant

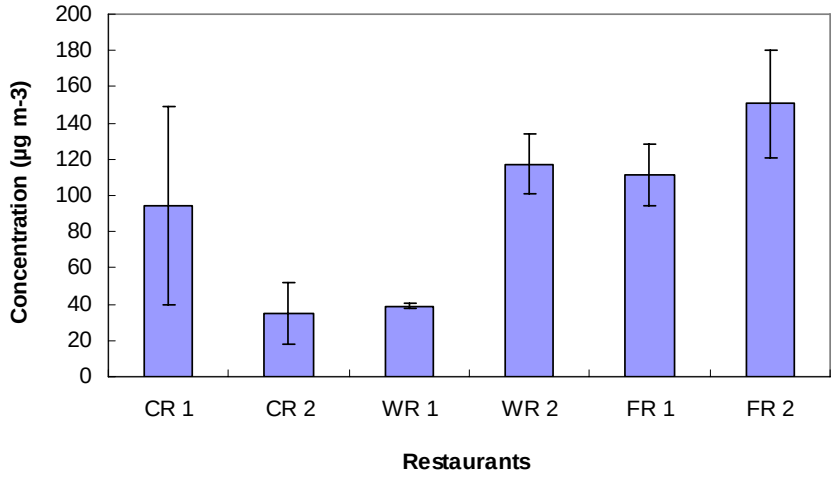


Figure 4-1-20 Mean concentrations of total particle phase organic compounds in each restaurant

Table 4-1-9 shows the concentrations of all the organic compounds listed above. Figure 4-1-21 shows the abundance of seven classes of organic compounds in particle

phase in each restaurant, including alkanes, fatty acids, PAHs, dicarbonxylic acid, alcohols, carbonyls and other tracer species for all commercial restaurants.

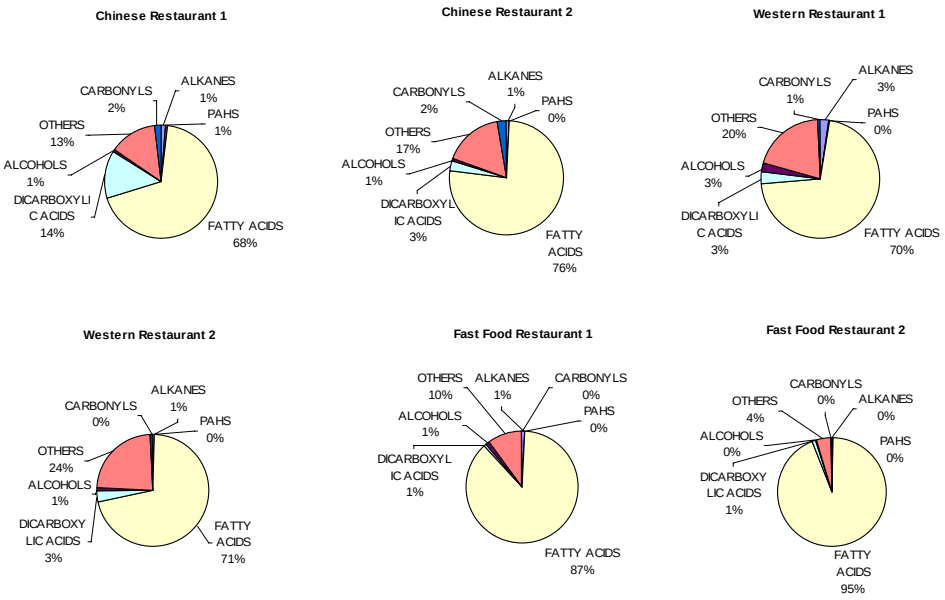


Figure 4-1-21 Chemical components measured for organic compounds in particle phase in commercial restaurants

It shows the abundance of different composition for all samples measured within commercial restaurants. Figure 4-1-21 does not show significant differences in emission patterns among different types of restaurants. Fatty acid is the most abundant organic group found at all sampling sites, especially in fast food restaurants, which contribute nearly 90% of total particle phase organic compounds. However, in Chinese and western restaurants, fatty acids contribute almost 80% of total organic compounds in particle phase. In addition, the percentages of “other species” are also high, which is the second abundant group.

Table 4-1-9 Average concentrations of organic compounds in commercial restaurants

Site	CR 1 (μgm^{-3})			CR 2 (μgm^{-3})			WR 1 (μgm^{-3}))			WR 2 (μgm^{-3})			FR 1 (μgm^{-3})			FR 2 (μgm^{-3})		
DICARBOXYLIC ACIDS	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D	Mean	N	S.D
Oxalic (GC2)	3.34	4	2.12	0.07	5	0.07	nd	5	nd	0.40	7	0.08	nd	5	nd	0.61	6	0.07
propanedioic (GC2)	0.29	4	0.16	0.03	5	0.04	0.03	5	0.01	0.06	7	0.02	0.01	5	0.01	0.08	6	0.04
butanedioic (GC2)	0.33	4	0.17	0.02	5	0.02	0.05	5	0.01	0.11	7	0.01	0.03	5	0.01	0.04	6	0.01
pentanedioic (GC2)	0.48	4	0.19	0.03	5	0.03	0.10	5	0.03	0.22	7	0.01	0.05	5	0.01	0.03	6	0.00
hexanedioic (GC2)	1.07	4	0.34	0.06	5	0.08	nd	5	nd	0.49	7	0.12	nd	5	nd	0.19	6	0.14
heptanedioic (GC2)	0.60	4	0.19	0.04	5	0.04	0.11	5	0.03	0.28	7	0.04	0.02	5	0.01	0.00	6	0.00
octanedioic (GC2)	1.31	4	0.43	0.09	5	0.09	0.17	5	0.04	0.55	7	0.08	0.12	5	0.03	0.01	6	0.01
nonanedioic (GC2)	3.63	4	1.26	0.42	5	0.25	0.31	5	0.07	1.16	7	0.23	0.28	5	0.06	nd	6	nd
decanedioic (GC2)	0.63	4	0.23	0.05	5	0.05	0.09	5	0.01	0.18	7	0.03	0.06	5	0.01	0.00	6	0.00
undecanedioic (GC2)	0.50	4	0.19	0.05	5	0.03	0.11	5	0.02	0.15	7	0.03	0.07	5	0.02	0.01	6	0.01
dodecanedioic (GC2)	0.27	4	0.09	0.03	5	0.03	0.06	5	0.01	0.09	7	0.02	0.05	5	0.03	0.03	6	0.01
tridecanedioic (GC2)	0.18	4	0.03	0.02	5	0.02	0.06	5	0.01	0.07	7	0.01	0.04	5	0.01	0.02	6	0.00
tetradecanedioic (GC2)	0.24	4	0.03	0.04	5	0.03	0.10	5	0.00	0.09	7	0.02	0.05	5	0.01	0.03	6	0.01
phthalic acid (1,2) (GC1)	nd	4	nd	nd	5	nd	nd	5	nd	0.04	7	0.02	nd	5	nd	0.00	6	0.00
isophthalic acid (1,3) (GC1)	nd	4	nd	nd	5	nd	0.00	5	0.00	nd	7	nd	nd	5	nd	0.01	6	0.00
terephthalic acid (1,4) (GC1)	nd	4	nd	nd	5	nd	nd	5	nd	nd	7	nd	0.01	5	0.01	0.00	6	0.00
Total Dicarboxylic Acid	12.85	4	5.43	0.95	5	0.76	1.18	5	0.23	3.90	7	0.67	0.79	5	0.18	1.07	6	0.24
ALCOHOLS																		
1-undecanol (C11)	0.01	4	0.00	0.02	5	0.04	0.01	5	0.01	nd	7	nd	0.01	5	0.00	0.01	6	0.00
1-dodecanol (C12)	0.06	4	0.02	0.03	5	0.01	0.30	5	0.19	0.09	7	0.01	0.02	5	0.01	0.05	6	0.02
1-tridecanol (C13)	0.03	4	0.01	0.01	5	0.00	0.10	5	0.02	0.04	7	0.00	0.01	5	0.00	0.02	6	0.01

1-tetradecanol (C14)	0.10	4	0.05	0.03	5	0.01	0.26	5	0.03	0.13	7	0.01	0.01	5	0.01	0.07	6	0.04
1-pentadecanol (C15)	0.04	4	0.01	0.01	5	0.01	0.04	5	0.00	0.08	7	0.02	0.02	5	0.01	0.03	6	0.01
1-hexadecanol (C16)	0.15	4	0.01	0.05	5	0.04	0.14	5	0.03	0.15	7	0.02	0.08	5	0.04	0.20	6	0.09
1-heptadecanol (C17)	0.02	4	0.01	0.01	5	0.00	0.02	5	0.00	0.03	7	0.01	1.11	5	0.63	0.08	6	0.03
1-octadecanol (C18)	0.08	4	0.03	0.02	5	0.01	0.06	5	0.01	0.06	7	0.00	0.04	5	0.02	0.07	6	0.02
1-nonadecanol (C19)	0.01	4	0.00	0.00	5	0.00	0.00	5	0.00	0.01	7	0.00	0.03	5	0.01	0.01	6	0.00
1-icosanol (C20)	0.03	4	0.02	0.00	5	0.00	0.01	5	0.00	0.01	7	0.00	0.01	5	0.00	0.00	6	0.00
1-heneicosanol (C21)	0.01	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	5	0.00	0.00	6	0.00
1-docosanol (C22)	0.01	4	0.00	0.00	5	0.00	0.02	5	0.00	0.01	7	0.00	0.00	5	0.00	0.00	6	0.00
1-tricosanol (C23)	0.00	4	0.00	0.00	5	0.00	nd	5	nd	0.00	7	0.00	0.00	5	0.00	0.00	6	0.00
1-docosanol (C24)	0.01	4	0.00	0.00	5	0.00	0.01	5	0.00	0.01	7	0.00	0.03	5	0.01	0.01	6	0.00
1-pentacosanol (C25)	0.00	4	0.00	0.00	5	0.00	0.00	5	0.00	0.00	7	0.00	0.00	5	0.00	0.00	6	0.00
1-hexacosanol (C26)	0.03	4	0.00	0.01	5	0.00	0.01	5	0.01	0.01	7	0.00	0.00	5	0.00	0.00	6	0.00
1-heptacosanol (C27)	0.00	4	0.00	0.00	5	0.00	nd	5	nd	0.00	7	0.00	0.00	5	0.00	0.00	6	0.00
1-octacosanol (C28)	0.06	4	0.01	nd	5	0.00	0.01	5	0.01	0.11	7	0.03	nd	5	nd	0.00	6	0.00
1-nonacosanol (C29)	nd	4	nd	nd	5	0.00	nd	5	nd	0.01	7	0.01	nd	5	nd	nd	6	nd
1-triacontanol (C30)	nd	4	nd	nd	5	0.00	nd	5	nd	0.02	7	0.01	nd	5	nd	nd	6	nd
1-hentriacontanol (C31)	nd	4	nd	nd	5	0.00	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
1-dotriacontanol (C32)	nd	4	nd	nd	5	0.00	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
Total Alcohol	0.66	4	0.19	0.20	5	0.12	0.99	5	0.28	0.77	7	0.06	1.38	5	0.71	0.56	6	0.21
OTHERS																		
glycerine	1.13	4	0.64	0.58	5	0.21	2.50	5	1.15	3.87	7	0.37	1.62	5	1.23	2.38	6	1.55
levoglucosan	0.32	4	0.15	0.94	5	0.81	0.24	5	0.07	1.87	7	2.39	0.05	5	0.01	0.50	6	0.12
monopalmitin (16:0)	2.05	4	0.88	0.69	5	0.17	1.74	5	0.08	8.73	7	0.63	4.40	5	0.93	1.51	6	1.11
monoolein (18:1)	1.76	4	0.57	1.50	5	2.31	0.81	5	0.14	2.02	7	0.10	3.63	5	0.87	1.40	6	0.36
monostearin (18:0)	0.72	4	0.28	0.24	5	0.08	0.75	5	0.01	4.39	7	0.65	0.75	5	0.19	0.29	6	0.15
cholesterol	1.23	4	0.46	0.46	5	0.11	0.97	5	0.08	2.66	7	0.28	0.33	5	0.10	0.54	6	0.08

ergosterol	nd	4	nd	nd	5	0.00	nd	5	nd	nd	7	nd	nd	5	nd	nd	6	nd
stigmasterol	1.76	4	0.28	0.63	5	0.29	0.33	5	0.01	1.72	7	0.10	0.08	5	0.03	0.03	6	0.01
b-sitosterol	2.93	4	0.45	0.99	5	0.46	0.57	5	0.08	2.89	7	0.19	0.11	5	0.06	0.12	6	0.02
Total	12.64	4	3.19	6.03	5	3.74	7.91	5	0.84	28.16	7	1.45	10.97	5	2.87	6.76	6	1.99
CARBONYLS																		
methylglyoxal (GC2)	0.15	4	0.05	0.02	5	0.02	0.04	5	0.01	0.13	7	0.10	nd	5	nd	0.02	6	0.00
glyoxylic acid (GC2)	nd	4	nd	0.03	5	0.01	nd	5	nd	nd	7	0.00	nd	5	nd	0.04	6	0.02
3-oxo-propanoic acid (GC2)	0.13	4	0.05	0.02	5	0.01	0.02	5	0.00	0.06	7	0.01	0.00	5	0.00	0.01	6	0.00
4-oxo-butanoic acid (GC2)	1.34	4	0.30	0.18	5	0.21	0.15	5	0.03	0.22	7	0.06	0.02	5	0.00	0.03	6	0.01
pyruvic (GC2)	0.04	4	0.01	0.00	5	0.00	nd	5	nd	0.03	7	0.01	0.00	5	0.00	0.03	6	0.01
nonanal (GC2)	0.26	4	0.01	0.58	5	0.33	nd	5	nd	0.13	7	0.11	0.03	5	0.03	0.11	6	0.09
Total Carbonyls	1.92	4	0.41	0.83	5	0.42	0.21	5	0.05	0.57	7	0.18	0.05	5	0.03	0.24	6	0.09

* S.D: standard deviation
* N: Number of samples
* nd: not detected

4.1.4 Emissions from Commercial Restaurants

4.1.4.1 Emission rates

It is important to assess the contribution of cooking fumes emission to air pollution in Hong Kong. In order to calculate the amount of pollutants emitted from commercial restaurants during peak period. The following equation is used:

Pollutants' peak emission = (Pollutants' concentration) * (l *w) *v*t

Where l= duct height (m) ; w= duct width (w); v = duct velocity (m/s); t = sampling duration (s)

In the study, samples were collected during the peak hours (over a 1.5 hr period) of commercial restaurants. In order to calculate the emission rate (mg/year) for each restaurant, it is assumed that it operated for 365 days per year and served 6 peak hours each day. The emission rates were calculated in the following table.

However, the Fast Food restaurant is a special case. The number of customers in the Fast Food restaurants was relatively stable. As a result, it is assumed that the Fast Food restaurants served 8 peak hours each day.

According to the statistics of Food and Environmental Hygiene Department, there are around 8000 general restaurants, including 263 of which that are Fast Food restaurants In this study, all restaurants except the fast food restaurants were categorized according to their names according to the database provided by FEHD. Restaurants were divided into four categories, Chinese restaurant, western restaurants, Japanese and Korea restaurant and southeast Asia restaurant. A summary is listed in the following table.

Table 4-1-10 All restaurants in four categories in Hong Kong

	Chinese Restaurant	Western Restaurant	Japanese and Korea restaurant	Southeast Asia restaurant
No. of restaurant	5050	1705	645	320

As samples from the restaurants fall in last two categories were not collected in this study, Japanese and Korea restaurant was treated as western restaurant while southeast Asia restaurant was treated as Chinese restaurant.

The annual emission rates on $PM_{2.5}$, gas phase and organic phase organic compounds for the commercial restaurants in Hong Kong were calculated and listed in table 4-1-11.

Table 4-1-11 Estimated pollutants emission rates from commercial restaurants

Commercial Restaurants	Average $PM_{2.5}$ mass Concentration ($\mu g\ m^{-3}$)	Exhaust Duct Volume (m^3)	Total $PM_{2.5}$ mass (mg)	Emission Rate (mg/year)	Average Emission Rate (mg/year)	No. of Restaurant	Total Emission (kg/year)
Chinese Restaurant 1	$0.51x10^3$	$7.23x10^4$	$3.72x10^4$	$5.42x10^7$	$3.97x10^7$	5370	$2.13x10^5$
Chinese Restaurant 2	$1.21x10^3$	$1.43x10^4$	$1.72x10^4$	$2.51x10^7$			
Western Restaurant 1	$0.14x10^3$	$1.21x10^4$	$1.63x10^3$	$2.39x10^6$	$3.60x10^6$	2350	$0.85x10^4$
Western Restaurant 2	$0.28x10^3$	$1.17x10^4$	$3.30x10^3$	$4.81x10^6$			
Fast Food Restaurant 1	$2.10x10^3$	$1.47x10^4$	$3.08x10^4$	$6.00x10^7$	$3.34x10^7$	263	$0.88x10^4$
Fast Food Restaurant 2	$0.30x10^3$	$1.17x10^4$	$3.49x10^3$	$6.79x10^6$			
Total							$2.30x10^5$
Commercial Restaurants	**Average Gas Phase PAH Concentration ($ng\ m^{-3}$)**	**Exhaust Duct Volume (m^3)**	**Total PAH mass (mg)**	**Emission Rate (mg/year)**	**Average Emission Rate (mg/year)**	**No. of Restaurant**	**Total Emission (kg/year)**
Chinese Restaurant 1	$3.03x10^3$	$7.23x10^4$	$8.75x10^2$	$3.19x10^5$	$1.89x10^5$	5370	$1.01x10^3$
Chinese Restaurant 2	$2.82x10^3$	$1.43x10^4$	$1.60x10^2$	$5.86x10^4$			
Western Restaurant 1	$1.07x10^3$	$1.21x10^4$	$0.52x10^2$	$1.88x10^4$	$7.62x10^4$	2350	$1.79x10^2$
Western Restaurant 2	$7.82x10^3$	$1.17x10^4$	$3.66x10^2$	$1.34x10^5$			
Fast Food Restaurant 1	$1.52x10^3$	$1.47x10^4$	$1.19x10^2$	$4.35x10^4$	$5.13x10^4$	263	$0.13x10^2$
Fast Food Restaurant 2	$2.59x10^3$	$1.17x10^4$	$1.62x10^2$	$5.90x10^4$			
Total							$1.21x10^3$
Commercial Restaurants	**Average Particle Phase PAH Concentration ($ng\ m^{-3}$)**	**Exhaust Duct Volume (m^3)**	**Total PAH mass (mg)**	**Emission Rate (mg/year)**	**Average Emission Rate (mg/year)**	**No. of Restaurant**	**Total Emission (kg/year)**
Chinese Restaurant 1	$7.50x10^2$	$7.23x10^4$	$2.16x10^2$	$7.90x10^4$	$3.98x10^4$	5370	$2.14x10^2$
Chinese Restaurant 2	$0.30x10^2$	$1.43x10^4$	1.71	$6.24x10^2$			
Western Restaurant 1	$0.74x10^2$	$1.21x10^4$	3.59	$1.31x10^3$	$8.19x10^2$	2350	1.92
Western Restaurant 2	$0.19x10^2$	$1.17x10^4$	0.89	$3.27x10^2$			
Fast Food Restaurant 1	$0.18x10^2$	$1.47x10^4$	1.40	$5.12x10^2$	$1.06x10^3$	263	0.28

Fast Food Restaurant 2	$0.70x10^2$	$1.17x10^4$	4.40	$1.60x10^3$			
Total							$2.16x10^2$
Commercial Restaurants	**Average Gas Phase Organic Compound mass Concentration ($\mu g\ m^{-3}$)**	**Exhaust Duct Volume (m^3)**	**Total Gas Phase Organic Compound mass (mg)**	**Emission Rate (mg/year)**	**Average Emission Rate (mg/year)**	**No. of Restaurant**	**Total Emission (kg/year)**
Chinese Restaurant 1	3.69	$7.23x10^4$	$2.67x10^2$	$3.90x10^5$	$2.45x10^5$	5370	$1.31x10^3$
Chinese Restaurant 2	4.79	$1.43x10^4$	$0.68x10^2$	$9.96x10^4$			
Western Restaurant 1	1.66	$1.21x10^4$	$0.20x10^2$	$2.93x10^4$	$1.22x10^5$	2350	$2.86x10^2$
Western Restaurant 2	12.58	$1.17x10^4$	$1.47x10^2$	$2.15x10^5$			
Fast Food Restaurant 1	5.15	$1.47x10^4$	$0.75x10^2$	$1.47x10^5$	$1.04x10^5$	263	$2.73x10^1$
Fast Food Restaurant 2	2.67	$1.17x10^4$	$0.31x10^2$	$6.07x10^4$			
Total							$1.62x10^3$
Commercial Restaurants	**Average Particle Phase Organic Compound mass Concentration ($\mu g\ m^{-3}$)**	**Exhaust Duct Volume (m^3)**	**Total Particle Phase Organic Compound mass (mg)**	**Emission Rate (mg/year)**	**Average Emission Rate (mg/year)**	**No. of Restaurant**	**Total Emission (kg/year)**
Chinese Restaurant 1	$0.94x10^2$	$7.23x10^4$	$6.80x10^3$	$9.93x10^6$	$5.33x10^6$	5370	$2.86x10^4$
Chinese Restaurant 2	$0.35x10^2$	$1.43x10^4$	$0.50x10^3$	$7.24x10^5$			
Western Restaurant 1	$0.39x10^2$	$1.21x10^4$	$0.50x10^3$	$6.86x10^5$	$1.34x10^6$	2350	$3.16x10^3$
Western Restaurant 2	$1.17x10^2$	$1.17x10^4$	$1.37x10^3$	$2.00x10^6$			
Fast Food Restaurant 1	$1.11x10^2$	$1.47x10^4$	$1.63x10^3$	$3.18x10^6$	$3.31x10^6$	263	$0.87x10^3$
Fast Food Restaurant 2	$1.51x10^2$	$1.17x10^4$	$1.76x10^3$	$3.43x10^6$			
Total							$3.26x10^4$

According to the above table, $PM_{2.5}$, total gas phase PAHs, total particle phase PAHs, total gas phase organic compounds and total particle phase organic compounds emitted from commercial restaurants in Hong Kong are measured to be $2.30x10^5$ kg/year, $1.21x10^3$ kg/year, $2.16x10^2$ kg/year, $1.62x10^3$ kg/year and $3.26x10^4$ kg/year, repectively. The emission rate of total gaseous phase PAH was about 5 times higher than the emission rate of total particle phase PAH. However, the emission rate for total particle phase organic compounds was nearly 20 times higher than that of total gas phase organic compounds.

It should be noted that the measurements in this study were only conducted in limited representative restaurants, i.e. the emission of only three types of restaurants (Chinese, western and fast food) were estimated. However, Hong Kong is a vibrant city famed for its great variety of food that represents the essence of local culture. The emission from commercial restaurants would be affected by the food served by the restaurant, the size of restaurant, the exhaust duct size… etc. Therefore the estimated annual emission rates of these air pollutants in the present study can only provide a general idea with a high degree of uncertainty.

4.1.4.2 Comparison of emissions from different restaurants

Emissions from different kinds of restaurants differ much. The pollutants' levels produced by different restaurants were listed in the following table.

Table 4-1-12 Pollutants' emissions from different restaurants

	Chinese Restaurant	**Western Restaurant**	**Fast Food Restaurant**
$PM_{2.5}$ Concentration (μg m^{-3})	0.86 $x10^3$	0.21 $x10^3$	1.20$x10^3$
Percentage (%)[a]	92.6	3.7	3.7
Gas Phase PAHs (ng m^{-3})	2.93$x10^3$	4.45$x10^3$	2.06$x10^3$
Percentage (%)	83.5	14.9	1.6
Particle Phase PAHs (ng m^{-3})	3.9$x10^2$	0.47$x10^2$	0.44$x10^2$
Percentage (%)	99.1	0.88	0.13
Gas Phase Organic Compounds (μg m^{-3})	4.24	2.12	3.91
Percentage (%)	80.9	17.7	1.4
Particle Phase Organic Compounds (μg m^{-3})	0.65$x10^2$	0.78$x10^2$	1.31$x10^2$
Percentage (%)	87.7	9.69	2.67

* a: percentage = The emissions of pollutant by one type of restaurant/total emission

According to the above table, it can be seen that Chinese restaurant has the highest concentrations of particle phase PAHs and gas phase organic compounds while the highest levels of $PM_{2.5}$ and particle phase organic compounds occurred in fast food restaurant. These differences may attribute to the different cooking styles, different materials… etc. However, Chinese restaurant has the highest percentage of emission, over 80%, because of its largest number. These findings suggested that control of emissions from Chinese restaurants would be more important than control of emission from other types of restaurants.

4.1.4.3 Comparison of emissions between restaurants and vehicles

Traffic has long been recognized as the major contributors to $PM_{2.5}$. The emission rate of $PM_{2.5}$ from vehicles was calculated in order to compare with the cooking sources. According to a previous study conducted in Environmental Protection Department in Hong Kong, it is found that the average vehicle-related $PM_{2.5}$ emission rates were measured to be 114.80 mg $veh^{-1}km^{-1}$, respectively. (Source: Final Report of Determination of Suspended Particulate & VOC Emission Profiles for Vehicle Sources in Hong Kong. http://www.epd.gov.hk/epd/english/environmentinhk/air/studyrpts) In addition, Transport Department in Hong Kong has provided the statistics data for the total road travel in the territory during the year 2005, 30.66 million vehicle-kilometres per day. (Source: The Annual Traffic Census 2005. http://www.td.gov.hk/FileManager/EN/Content_1373). Consequently, the annual total $PM_{2.5}$ emission rates were calculated to be 1284.72 ton/year. These results suggest that the emission rate of $PM_{2.5}$ from commercial restaurants was approximately **17.9%** of that from vehicles.

PAHs have also been identified as major emission pollutants from petrol- and diesel-powered vehicles in urban atmospheres for a long time. As a result, the emission rate of PAHs from vehicles was also estimated to assess the importance of cooking sources. According to the same study mentioned before, the average vehicle-related gaseous phase and particle phase PAHs emission rates were 1174.88 μg $veh^{-1}km^{-1}$ and 105.57 μg $veh^{-1}km^{-1}$, respectively. (Source: Final Report of Determination of Suspended Particulate & VOC Emission Profiles for Vehicle Sources in Hong Kong. http://www.epd.gov.hk/epd/english/environmentinhk/air/studyrpts) Consequently, the

annual total gaseous and particulate PAHs emission rates were calculated to be 13147.96 kg/year and 1181.42 kg/year, respectively. These results suggest that the emission rate of gaseous PAHs from commercial restaurants was approximately **9.2%** of that from vehicles. As far as particulate PAHs are concerned, the emission rate from commercial restaurants was approximately **18.3%** of that from vehicles.

Based on the results above, the commercial cooking sources are less important than vehicular traffic source in contributing to $PM_{2.5}$ and PAH emissions, accounting for only about 10%. However, emissions from residential dwellings were not estimated in this study. It is believed that home kitchens might also play an important role in PAH emissions into the urban atmosphere (Li et al., 2003), because of the dense population in Hong Kong

4.2 Residential Dwellings

4.2.1 Air Exchange Rate and CO_2 concentrations

Air exchange rate was used to estimate the ventilation of a room. In this study, it was defined as the ratio between the fresh air supply rate in unit volume per hour to the effective volume of the sampling room. The tracer gas technique involves injecting a tracer gas and mixing it through the house, then measuring its decay rate with an appropriate instrument. If exfiltration rates of the tracer gas are constant, mixing is uniform, the chemicals are negligible and no indoor source of the gas is operating, the AER a, can be calculated from the following equation (Nantka, 1990):

$$a = \frac{1}{t} \ln \frac{C_t}{C_0} \qquad (1)$$

Where t is time, C_t and C_0 are concentrations of the gas at times t and 0, respectively. Equation 1 was used to calculate the AER of the kitchen in the residential dwellings in this study based on measured CO_2 decay rates.

The real time CO_2 concentration monitoring was carried out by a Q Trak (TSI 8554). The AER found for the residential dwelling is measured to be 4.13 ± 2.21 h^{-1}. It should be noted that the AER calculated here is based on CO_2 decay rate; however, there are many factors that can influence the indoor CO_2 concentration. For example, person breath, outdoor sources, etc…Therefore the estimated AER for the residential dwelling in this study can only provide a general idea with high degree of uncertainty.

The following table 4-2-1 shows the CO_2 concentrations during two different cooking tests. The average CO2 concentration during deep frying and stir frying were

1521±246 ppm and 1769±400 ppm respectively. The peak CO2 concentration measured for deep frying and stir frying were 3056±727 ppm and 3409±1092 ppm. Deep frying was capable to elevate the indoor CO_2 concentration by a factor of 2.49 while stir frying can increase the CO_2 concentration 2.63 times. From this table, it can be seen that stir frying generally produce more CO_2 than deep frying.

Table 4-2-1: CO_2 concentrations during cooking

	N	Background Concentration (ppm)		Average Concentration (ppm)		Peak Concentration (ppm)		Ratio (Average/Background)	
		Medium	S.D	Medium	S.D	Medium	S.D.	Medium	S.D.
Deep Fry	9	619	55	1521	246	3056	727	2.49	0.51
Stir Fry	8	683	68	1769	400	3409	1092	2.63	0.67

* N: number of sample
* S.D: standard deviation

Figure 4-2-1 and figure 4-2-2 show an example of the real-time CO_2 concentrations during deep frying and stir frying. During deep frying, there are seven peaks in the figure. The first peak occurred when the fire lighted. This high CO_2 concentration was probably caused by the fuel (Liquefied Petroleum Gas) combustion. The second CO_2 peak concentration occurred about 2.5 minutes after fire ignition, and the other peaks occurred every five minutes late. CO_2 concentration will reach a peak when we turned the pork chop around and started to deep fry the other side.

However, the CO_2 concentration curve for stir frying is quite different. CO_2

concentration reached as high as 3500 ppm when the fire lighted. This high concentration was also caused by the fuel combustion. Then, CO_2 concentration maintained at a relatively high level during stir frying. No clear peaks can be observed in figure 4-2-2.

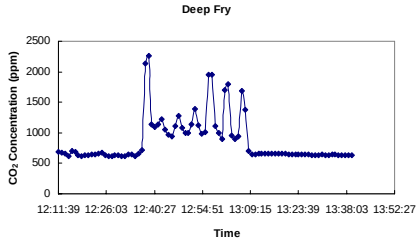


Figure 4-2-1: Real time CO_2 concentrations during deep frying

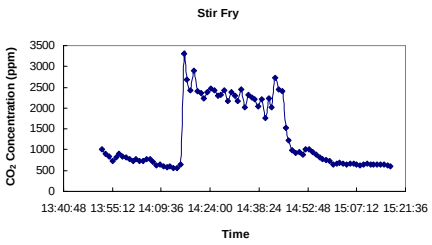


Figure 4-2-2: Real time CO_2 concentrations during stir frying

The 8-h average CO_2 levels (i.e., 1000 ppm) are specified by *Recommended Indoor Air Quality Objectives for Office Buildings and Public Place in Hong Kong* (HKIAQO, HKEPD, 1999). From table 4-2-1, it can be seen that the average CO_2 concentrations during both cooking processes exceeded this standard set by HKIAQO. The peak CO_2 level for stir frying was even 3 times higher than this requirement.

4.2.2 $PM_{2.5}$ mass concentration

Cooking has a drastic effect on the muscle tissue and fat (Rogge, et al., 1991). Compounds are released during meat cooking that are formed by oxidation, decarboxylation, fragmentation, recombination, rearrangement, condensation, and cyclization reactions of the precursor raw meat components (Frankel, E.N., 1982, Baines and Mlotkiewicz., 1983).

The real time $PM_{2.5}$ concentration monitoring was carried out by a Dust Trak (TSI 8520). In addition, a BGI Mini volume sampler with Teflon filter was also used to measure the $PM_{2.5}$ mass concentration. The relationship of average $PM_{2.5}$ concentrations derived from the DustTrak and the BGI Mini volume sampler was examined using linear regression method. The concentrations were in reasonable agreement and the correlation was high (R^2=0.84). The result in this study showed that the DustTrak air monitor can be used in cooking studies, but needs careful calibrations with the filter method. Figure 4-2-3 shows the relationship between these two methods.

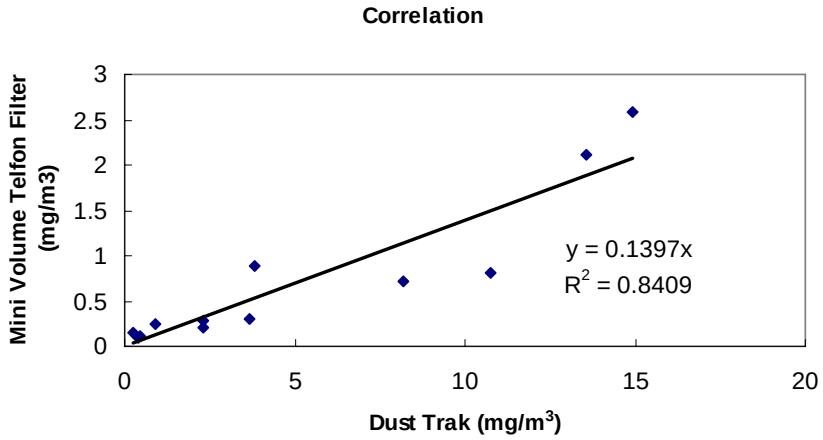


Figure 4-2-3 Correlation between Mini Volume and Dust Trak

Figure 4-2-4 and figure 4-2-5 show an example of the real-time $PM_{2.5}$ concentrations during deep frying and stir frying. Figures 4-2-4 clearly showed six peaks during deep frying pork chops. The first peak occurred about 2.5 minutes after the fire was lighted, and the other peaks occurred every five minutes late. It can be concluded that the $PM_{2.5}$ concentration will reach a peak when we turned the pork chop around and started to deep fry the other side. However, because the mass, fat content, moisture content of each piece of pork chop are different, the peak $PM_{2.5}$ concentration for each pork chop varied significantly.

However, the real time $PM_{2.5}$ concentration during stir frying is quite different from that of deep frying. There are several peaks in the figure; but the peaks can not match well with the cooking activities. However, it can be seen from these two figures that the $PM_{2.5}$ concentrations during stir frying maintained at a relatively higher level when compared to deep frying.

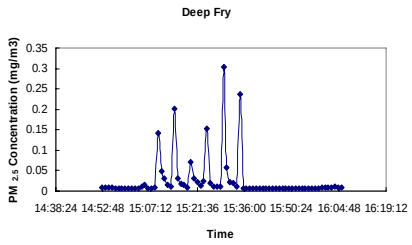


Figure 4-2-4 Real time $PM_{2.5}$ concentrations during deep frying

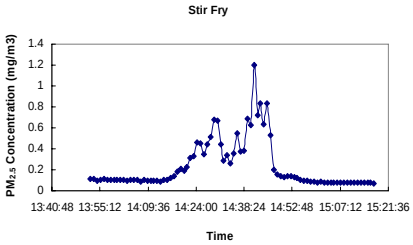


Figure 4-2-5 Real time $PM_{2.5}$ concentrations during stir frying

By using gravimetric methods, the average $PM_{2.5}$ mass concentrations for deep frying and stir frying pork chops were measured to be 0.225 ± 0.114 mg m^{-3} and 0.482 ± 0.308mg m^{-3}. As the background $PM_{2.5}$ levels were 0.032 ± 0.012 mg m^{-3}, it is found that there was an increase over the background by 7 and 15 during deep frying and stir frying, respectively. Although less oil is used in the stir frying process, $PM_{2.5}$ concentration of stir frying is nearly twice higher than that of deep frying. This may attribute to the pork chops. Pork chops were covered by the bread crumbs when they were poured into the wok during deep frying. As a result, they were not very humid and less particles were produced. This indicates that cooking style has a large impact on $PM_{2.5}$ emission, even more important than the raw materials used. The United States Environmental Protection Agency (USEPA) has established the $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) at 15 μg m^{-3} for the annual standard (3 year average of the annual arithmetic mean concentrations) and at 65 μg m^{-3} for the 24 h standard (3 year of the 98^{th} percentile of 24 h concentrations). As a result, the average concentrations during deep frying and stir frying may result in excedence of

the standard if cooking activity is sufficiently long.

A study conducted in Australia (He et al., 2004) found that the mean indoor $PM_{2.5}$ concentrations will rise to 0.745 mg/m^3 and 0.718 mg/m^3 during frying and grilling. The $PM_{2.5}$ concentrations in those studies are much higher than that of in this study. Another study conducted by Wallace (Wallace et al., 2004) presented that levels of $PM_{2.5}$ were increased during cooking by a factor of 3, which is lower than in this study. The difference was probably derived from various food ingredient, different cooking styles and different sampling methods.

4.2.3 Particle number and volume concentrations

Cooking, particularly frying, is an important indoor source of ultrafine particle (smaller than 0.1 micron diameter) which usually form the bulk of particle number but contribute only negligibly to particle mass (He et al., 2004, Abt et al., 2000, Wallace et al., 1996, Kamens et al., 1991).

In this study, Ultrafine (smaller than 0.1 micron diameter) particle number concentrations were measured simultaneously in the kitchen by using a P Trak (TSI Model 8525). The P trak has provided a primary determination of the number of particles (smaller than 0.1 μm) per unit volume. The volume of these particles was determined by assuming sphericity and multiplying the number of particles by $\pi d^3/6$. The diameter used for calculations was the logarithmic midpoint (geometric mean) of these bins boundaries. Thus, measured particle characteristics can be expressed as volume concentrations ($\mu m^3 cm^{-3}$)

Table 4-2-2 presents the ultrafine particles number and volume concentrations measured by P Trak during cooking. The average particle number concentration will rise to $2x10^5 \pm 7.3x10^4$ pt/cc and $1x10^6 \pm 5.1x10^5$ pt/cc during deep frying and stir frying respectively. The peak particle number concentration measured for deep frying and stir frying were $3.5x10^5 \pm 1x10^5$ pt/cc and $1.5x10^6 \pm 8.2x10^5$ pt/cc. It is also observed that deep frying and stir frying can elevate indoor particle number concentrations by a factor of 8 and 48, respectively. These findings are consistent with the aforementioned studies which have identified cooking contributed primarily to

ultrafine particles. It is found that stir frying can generate five times more ultrafine particles than that of deep frying.

He (He et al., 2004) found that the indoor concentrations were 15 times higher during cooking, frying, grilling, toasting, cooking pizza and stove use. Wallace (Wallace et al., 2004) also found that particle production during cooking is heavily weighted toward the ultrafine particles. The smallest ultrafine (10-18nm) were elevated by factors of 13-14 over background and the next smallest category (18-50nm) by factors of 7-9, whether number or mass concentrations are the metric. Cooking-related concentrations of the remaining sub-micrometer particle size categories were increased by factors ranging from 1.2 to 5.8. Morawska (Morawska et al., 2003) also reported that particle levels were up to 100 times higher than the background level during cooking activities. The ratios measured in this study are different from all these studies. The difference is reasonable, as many factors were different in those studies. For example, house characteristics, fuel composition, air exchange rate, as well as cooking methods and cooking materials.

According to the following table, the average particle volume concentrations were measured to be 13.19 ± 4.75 $(\mu m/cm)^3$ and 65.52 ± 33.33 $(\mu m/cm)^3$ during deep frying and stir frying respectively. The results can be compared with those presented in the literature. Abt (Abt et al., 2000) has reported the volume concentration of $PM_{(0.02\text{-}0.5)}$ for many indoor activities. The concentrations for sautéing, frying, tosting and barbecuing were measured to be 42.71 ± 21.12 $(\mu m/cm)^3$, 28.85 ± 15.33 $(\mu m/cm)^3$, 45.90 ± 53.44 $(\mu m/cm)^3$, 57.39 ± 37.55 $(\mu m/cm)^3$, respectively. Another

study (Wallace et al., 2004) found that during cooking, the volume concentration for particles in the 0.01-0.1 μm category were around 7.5 $(\mu m/cm)^3$, which is much lower than the results presented in this study. This variability may attribute to the difference in house characteristics, air exchange rate and cooking methods.

Table 4-2-2 Ultrafine particle numbers and volume concentrations during cooking

	N	Background Concentration		Average Concentration		Peak Concentration		Ratio (Average/Background)	
		Medium	S.D	Medium	S.D	Medium	S.D.	Medium	S.D.
					Number Concentration (pt/cc)				
Deep Fry	9	$2.5x10^4$	$6x10^3$	$2x10^5$	$7.3x10^4$	$3.5x10^5$	$1x10^5$	8	5
Stir Fry	7	$2.1x10^4$	$5.2x10^3$	$1x10^6$	$5.1x10^5$	$1.5x10^6$	$8.2x10^5$	48	18
					Volume $(\mu m/cm)^3$				
Deep Fry	9	1.62	0.39	13.19	4.75	23.20	6.69	8	5
Stir Fry	7	1.35	0.34	65.52	33.33	100.38	53.66	48	18

Note: N: Sample number;
S.D: Standard Deviation

Two previous studies (Dennekamp et al., 2001, Wallace, et al., 2000) provided useful data on ultrafine particle number concentrations during cooking. Both studies showed that the gas burner alone or an electric stovetop heating element alone could produce copious numbers of ultrafine particles even in the absence of pots, water, or food being cooked. The findings in this study are consistent with the conclusion in those two studies.

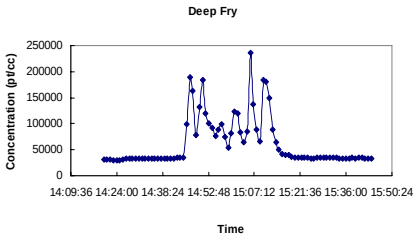


Figure 4-2-6 Real time particle counts during deep frying

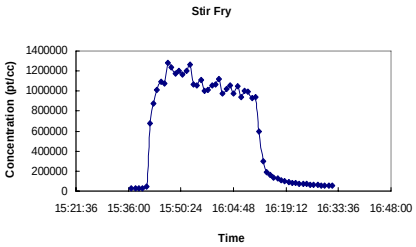


Figure 4-2-7 Real time particle counts during stir frying

Figure 4-2-6 and figure 4-2-7 show an example of the real-time ultrafine number concentrations during deep frying and stir frying. Like $PM_{2.5}$ mass concentration, six peaks were found during deep frying pork chops. The first peak also occurred about 2.5 minutes after the fire was lighted, and the other peaks occurred every five minutes late. However, particle number concentrations maintained at a high level during stir frying. No clear peak can be found either.

4.2.4 Particle size distribution

4.2.4.1 Particle number concentration

Particles in different size ranges were measured by Met One. Met One 9012 Ambient Aerosol Particulate Profiler (Met One) is a low flow (2.83 Litre/min) optical light scatter PM monitoring machine that used a laser diode based optical sensor to convert scattered light to numbers of particles per size range. As a PM monitor, particles are detected, sized and counted in six size ranged from 0.3 to 10 μm which can be selected. In addition, the sampling time intervals can as low as 2 seconds to quantify rapid changes in aerosol concentration. Met One can measure the particles in several ranges, 0~0.3 μm, 0.3~0.7μm, 0.7~1μm, 1~2μm, 2~3μm and 3~4μm.

Table 4-2-2 presents the six range particles number and volume concentrations measured by Met One during cooking. For deep frying, the particles number concentration has a trend that 0.3μm (6097.1 pt/ft^3)>0.7μm (4817.3 pt/ft^3)>1μm (3563.1 pt/ft^3)>2μm (503.2 pt/ft^3)>4μm (364.5 pt/ft^3)>3μm (228.2 pt/ft^3). While for stir frying, the trend is different, that is, 1μm (15975.5 pt/ft^3)>0.7μm (13916.5 pt/ft^3)>0.3μm (12936.5 pt/ft^3)>2μm (2914.5 pt/ft^3)>4μm (2738.5 pt/ft^3)>3μm (1419 pt/ft^3). The number concentrations of particles in all size ranges during stir frying were higher than that from deep frying. Stir frying can elevate indoor particles (0.7~1μm) concentration by a factor of 17 while deep frying can only rise 4 times.

The volume distribution ranges over 3 orders of magnitude. For deep frying, it has a peak (8179 μm^3/ft^3) at 4 μm, and a second peak (1866 μm^3/ft^3) at 3μm. For stir

frying, the volume concentration has a nearly identical distribution, with a peak (61446 $\mu m^3/ft^3$) at 4 μm, and a second peak (11603 $\mu m^3/ft^3$) at 3μm.

Liao (Liao et al., 2006) also reported that the indoor PM concentration during Chinese cooking. A relatively high volume concentration was also found for the coarse particles. However, the overall orders of magnitudes of PM concentrations were different from those reported by Liao (Liao et al., 2006) and Abt (Abt et al., 2000). The difference might be related to the cooking strategy and ventilation rate in the residential dwellings in Hong Kong.

Table 4-2-3 Number and volume concentrations of both cooking episodes (Met One)

	Deep Frying			Stir Frying			Background Concentration		Ratio (Average/Background)	
	N	Medium	S.D	N	Medium	S.D	Medium	S.D	Deep frying	Stir frying
					Number Concentration (ft^{-3})					
0.3μm	3	6097.1	10.5	1	12936.5	nd	1912.5	1768.5	3	7
0.7μm	3	4817.3	36.3	1	13916.5		1350.0	1166.9	4	10
1μm	3	3563.1	1.6	1	15975.5		967.5	513.8	4	17
2μm	3	503.2	31.9	1	2914.5		180.0	21.6	3	16
3μm	3	228.2	1.6	1	1419		105.0	9.6	2	14
4μm	3	364.5	0.9	1	2738.5		191.0	14.2	2	14
					Volume Concentration ($\mu m/ft)^3$					
0.3μm	3	10.8	0.0	1	22.8	nd	3.4	3.1	3	7
0.7μm	3	315.1	2.4	1	910.4		88.3	76.3	4	10
1μm	3	1145.1	0.5	1	5134.4		310.9	165.1	4	17
2μm	3	888.8	56.4	1	5147.7		317.9	38.2	3	16
3μm	3	1866.2	13.1	1	11603.3		858.6	78.2	2	14
4μm	3	8179.0	20.5	1	61446.2		4285.6	319.2	2	14

Note: N: Sample number;
S.D: Standard Deviation

Figure 4-2-8 and 4-2-9 show an example of the real time particle number concentrations during deep frying and stir frying. From this picture, it can be seen that the number concentrations for particles of 2μm, 3μm and 4μm were relatively low. The number concentrations for 0.3μm, 0.7μm and 1μm suddenly increased after the fire was ignited. For stir frying, six peaks were found during the cooking experiment, the first peak occurred about 2.5 minutes after the fire was lighted, and the other peaks occurred every five minutes late. It can be concluded that the particles number concentration will reach a peak when we turned the pork chop around and started to

fry the other side. Although the mass, fat content, moisture content of each piece of pork chop are different, the peak particle number concentrations did not vary much. However, for deep frying, several peaks were found in the figure, the peaks can not match well with the cooking activities.

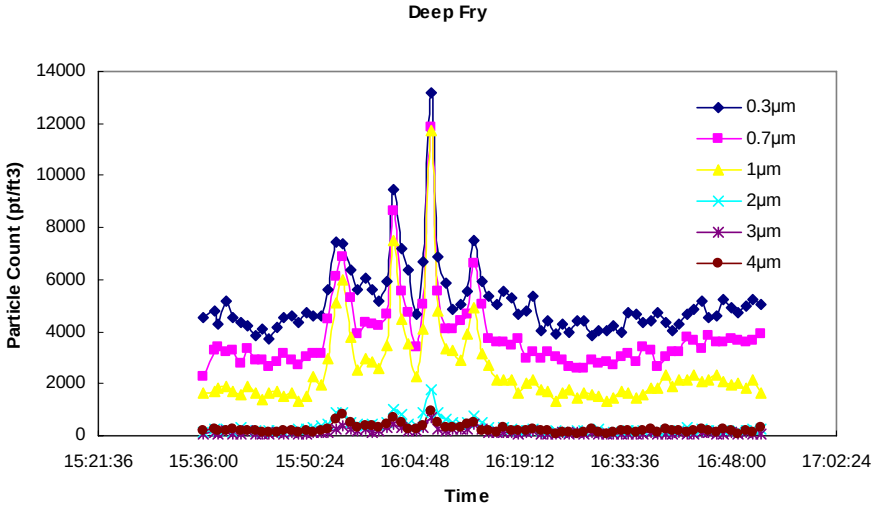


Figure 4-2-8 Real time particle counts during deep frying (Met One)

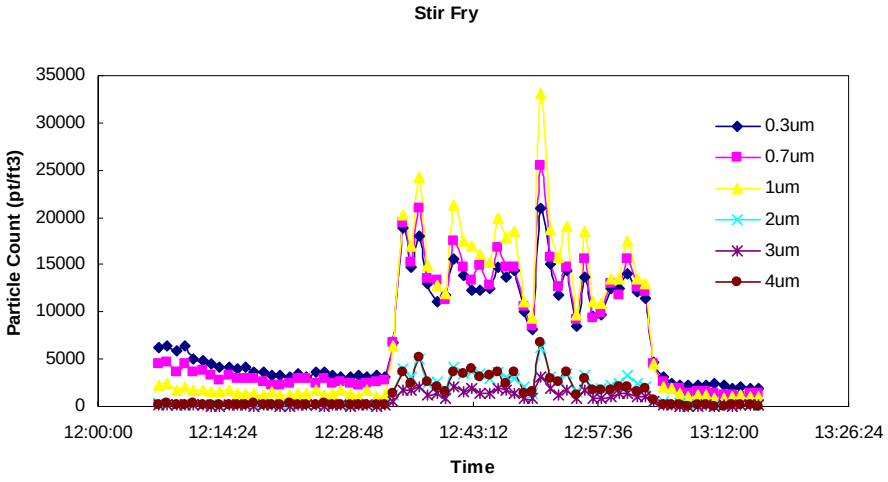
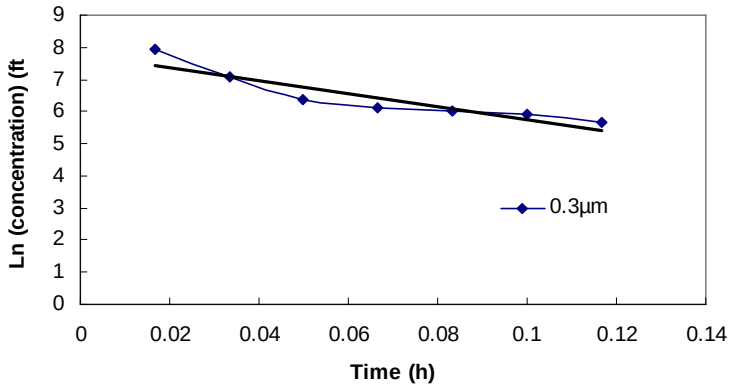
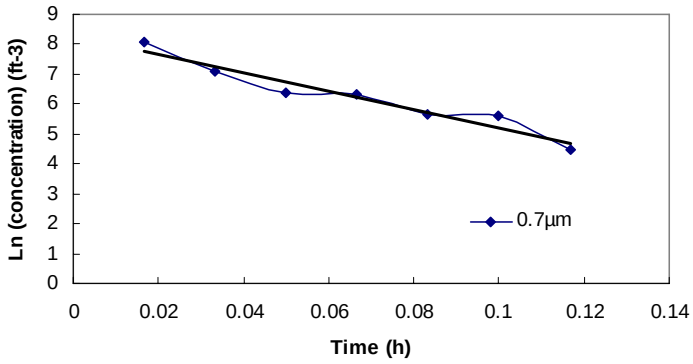


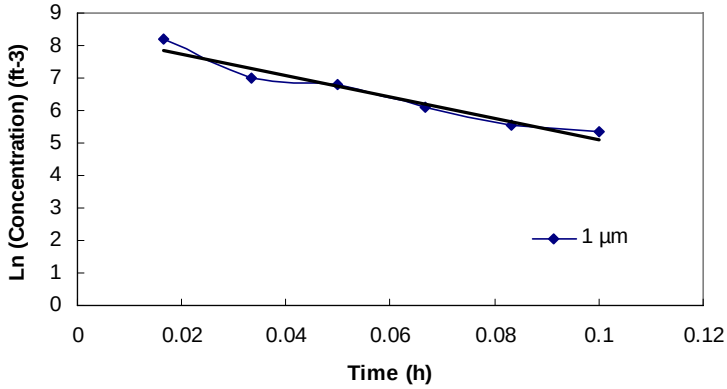
Figure 4-2-9 Real time particle counts during stir frying (Met One)

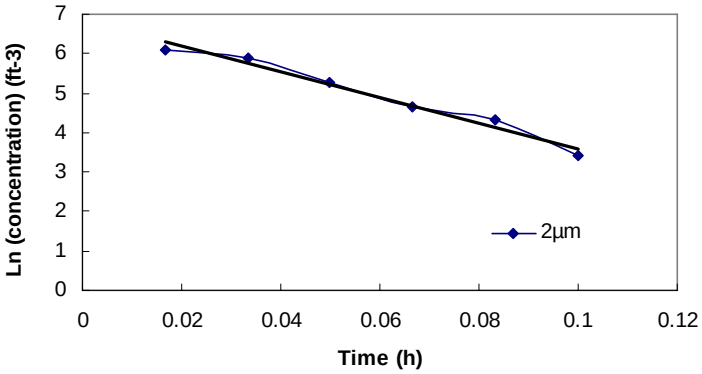
4.2.4.2 Particle decay rate

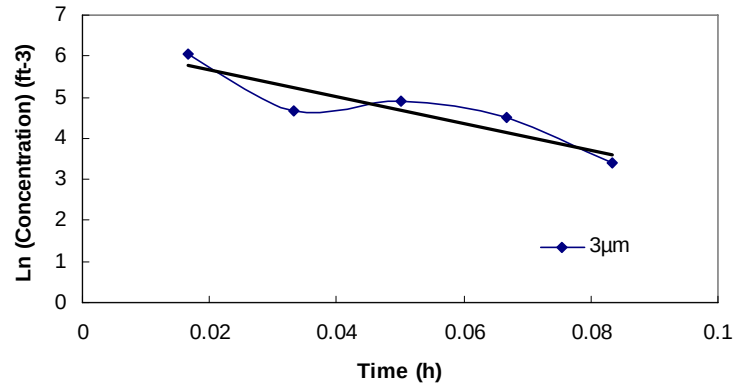
The size-dependent decay rate estimate (including deposition and air exchange rates) from cooking events were calculated by their decay curve. Figure 4-2-10 show the decay curve for particles of different size range. For particles 0.3μm, 0.7μm, 1μm and 2μm, the decay curve is generally linear and R^2 values were relatively high. It is evident that there is variability in the deposition rate estimations in that a greater variability appears in the particles larger than 2 μm. This variability may be due to the inputs of model parameter such as Brownian diffusion, whereas in the realistic conditions the housing structure, the dominate flow regimes, deposition surface materials, coagulation of smaller particles, indoor and outdoor temperature, and room air mixing patterns that occurs while particles are decaying also result in the variability. (Liao et al., 2006)




Ln (concentration) (ft-3)
9
8
7
6
5
4
3
2
1
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Time (h)
0.7µm


Ln (Concentration) (ft-3)
9
8
7
6
5
4
3
2
1
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Time (h)
1 µm


Ln (concentration) (ft-3)
7
6
5
4
3
2
1
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Time (h)
2µm



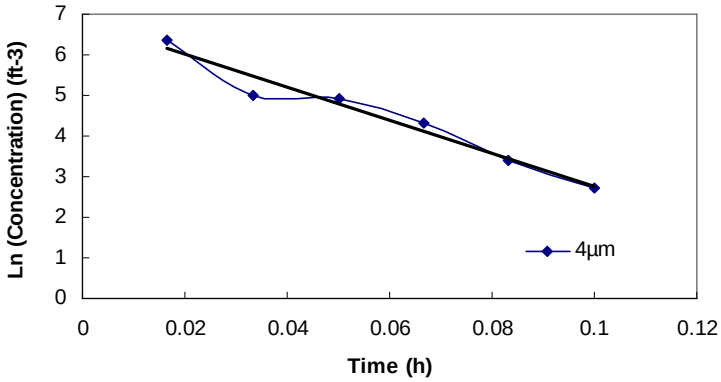


Figure 4-2-10 Plot of the decay of PM when the cooking event is stopped where data are represented as the natural logarithm of concentration-time profile

Figure 4-2-11 shows the relationship between the deposition rates and the particle size. It indicates that the deposition rates increase with particle size, with mean deposition rates of 20.224 h^{-1} for 0.3μm particles, increasing up to 40.687 h^{-1} for 4μm particles. This increase in deposition rates with particle size is expected since gravitational settling is the dominant mechanism for particles in these size ranges. The

same trend is found by Liao (Liao et al., 2006). However, the deposition rate measured in this study is much higher than those measured by Liao. This significant variability existing in estimates may be due to the exhaust fan, differences in house temperature gradients, surface materials, airflow patterns, and volumes. As the measured deposition rates were much higher, suggesting that concentration and/or temperature gradients created by cooking events may increase the mixing rate of room air resulting in higher deposition rates of particles to surfaces.

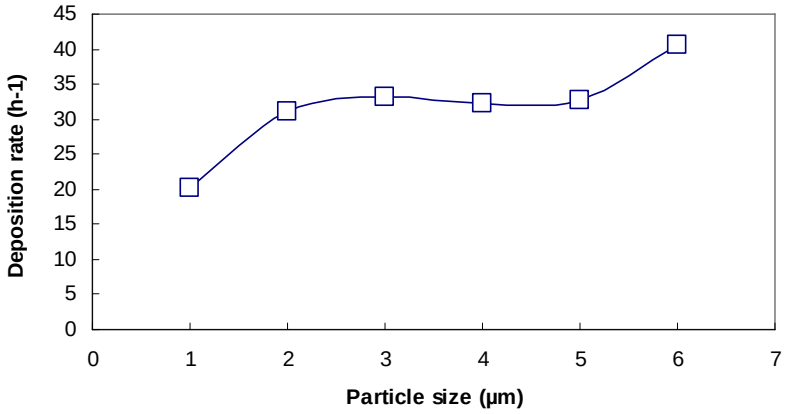


Figure 4-2-11 Deposition rate estimates from cooking event for different particle size range

4.2.5 Source emission rates and emission factors

As have mentioned in "*Methodology*" section, deep frying and stir frying pork chops emission rate and emission factors were calculated based on the equation,

$$Q_S = \frac{V(\alpha + k)\Delta C_{in}}{[1 - \exp(-(\alpha + k)\Delta t)]} \quad (2)$$

Where ΔC_{in} = the change of indoor mass or number concentration of particle (mg/m^3 or pt/cc), a= air exchange rate (h^{-1}), k= k_1+k_2, k_1 is the natural decay rate of the particle when the stove is turned off, and k_2 is the additional decay rate when the fan is on, V= efficient volume of the building (m^3), Qs= indoor particle generation rate (mg/hr or pt/hr), t= time (hr).

Determine the decay rate for the given particle size is the first thing. This is done by determining the background concentration, subtracting the background from all of the elevated values following cooking, transforming to logarithms, and carrying out a regression analysis over time. Figure 4-2-12 shows an example of the decay curve for deep frying and stir frying after cooking was ceased as measured by P trak for ultrafine particles.

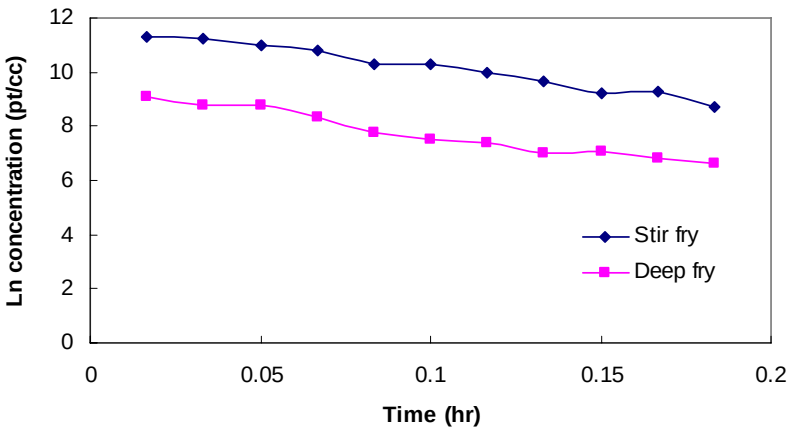


Figure 4-2-12 Particle decay curve for deep frying and stir frying

From the figure above, it can be seen that the particle decay curves are relatively straight, and the negative slope of the regression is a+k. Apply the equation mentioned above, the mean source emission for deep frying and stir frying were calculated and listed in table

Ultrafine particle emission rates and emission factors reported here are compared with other cooking studies in Table 4-2-3 and Table 4-2-4. For ultrafine particle number emissions, as can be seen in table 4-2-3, the emission rate from stir frying pork chop was calculated to be 8.57×10^{13} pt/hr $\pm$ 6.51×10^{13} pt/hr, which was nearly seven times higher than that from deep frying. The emission rate derived from this study can be compared with those presented in the literature. The particle number emission rates measured during this study were in the same range of all the other studies portrayed.

For $PM_{2.5}$ emissions, the emission rate of 6.91 mg hr^{-1} $\pm$ 7.62 mg hr^{-1} and 41.1 mg

h^{-1} ±2.39 mg hr^{-1} resulting from deep frying and stir frying pork chop found in this study are comparable to the results presented in the literature. It can also be observed that stir frying can generate about five times more $PM_{2.5}$ mass than deep frying. These findings are consistent with previous studies (Abt et al., 2000, Wallace et al., 2004) that cooking was capable of producing copious ultrafine particles which contribute less to mass.

Table 4 shows estimates of particle number emission factors in this study and those presented in literature. However, for particle number emission, it is difficult to compare these data with the literature, as there is very limited information available on particle number emission factors.

A study sponsored by the California Air Resources Board (Fortmann et al., 2002) employed an electrical mobility particle monitor with 12 size bins from 0.03 to 10 μm in diameter. The investigators also collected particles on filters using a low-flow $PM_{2.5}$ monitor. One of these experiments included frying tortillas in oil on a gas stove. The investigators calculated an energy use of 5000kJ for the tortilla cooking experiments and a corresponding $PM_{2.5}$ source strength of 38 μg/kJ. Wallace (Wallace et al., 2004) also reported the source strength of 10μg/kJ in his tortilla experiments. These calculations of source strengths per time of cooking or per energy used have quite wide uncertainties, due to different methods of cooking, different temperatures of the cooking oil, etc. Indoor air quality models employing the source strength estimated in these studies will need to take into account this extreme variability.

$PM_{2.5}$ emission factor in this study are measured to be 8.64 mg/kg pork and 51.38

mg/kg pork for deep frying and stir frying, respectively. However, the values are much lower than those reported in other studies. The difference is not surprising, taking that cooking methods, sampling technology in these studies are totally different. Those studies were all conducted in a laboratory not in a real residential dwelling. Either a dilution source sampling system or EPA impinger method was applied for collecting samples. In addition, those studies were all carried out in the U.S.A, and focus on the emission of meat charbroiling. Charbroiling is a traditional American cooking style which is not directly applicable to Hong Kong.

Table 4-2-4 Comparison of particle emission rates between the present study and previous cooking studies

Particle Number			
Cooking Test	**Emission Rate (particle $hr^{-1}x10^{13}$)**		**Source**
	Mean	**S.D**	
Deep Frying Pork Chop	1.16	0.53	present study
Stir Frying Pork Chop	8.57	6.51	present study
Cooking	3.4	5.16	He et al., 2004
Cooking Pizza	0.99		He et al., 2004
Frying	2.85	1.47	He et al., 2004
Grilling	4.4	3.03	He et al., 2004
Stove	4.4	30.84	He et al., 2004
Toasting	4.05	10.02	He et al., 2004
Gas Stove	around 50		Wallace et al., 2004
$PM_{2.5}$ mass Concentration			
Cooking Test	**Emission Rate (mg hr^{-1})**		**Source**
	Mean	**S.D**	
Deep Frying Pork Chop	6.91	7.62	present study
Stir Frying Pork Chop	41.1	2.39	present study
Cooking	6.6	59.4	He et al., 2004
Cooking Pizza	95.4		He et al., 2004
Frying	160.8	130.8	He et al., 2004
Grilling	166.8	1068	He et al., 2004
Stove	14.4	77.4	He et al., 2004
Toasting	6.6	22.2	He et al., 2004
Cooking	102	36	Wallace et al., 1996

*S.D: standard deviation

Table 4-2-5 Comparison of particle emission factors between the present study and previous cooking studies

Particle Number			
Cooking Test	**Emission Factor (particle $kg^{-1}x10^{13}$)**		**Source**
	Mean	**S.D**	
Deep Frying Pork Chop	1.45	0.66	present study
Stir Frying Pork Chop	10.71	8.14	present study
$PM_{2.5}$ mass Concentration			
Cooking Test	**Emission Factor (g/kg)**		**Source**
	Mean	**S.D**	
Deep Frying Pork Chop	8.64 (mg/kg)	9.52	present study
Stir Frying Pork Chop	51.38 (mg/kg)	2.99	present study
Charbroiler hamburger	15		McDonald et al., 2003
Charbroiler hamburger	32.7		Norbeck et al., 1997
Charbroiler hamburger	40		Hildemann et al., 1991
Charbroiler hamburger	18		Schauer et al.,1999
Auto-Charoilier hamburger	4.5		McDonald et al., 2003
Auto-Charoilier hamburger	7.4		Norbeck et al., 1997
Charbroiler chicken with skin	7.2		McDonald et al., 2003
Charbroiler chicken with skin	10.4		Norbeck et al., 1997

*S.D: standard deviation

4.2.6 Comparison between cooking and other sources

Epidemiological studies had reported that smoking, burning incenses, mosquito coils, and candles and using combustion devices are also sources of indoor air pollutant. It is also reported that burning incenses, mosquito coils, and candles cause indoor air pollution akin to that from cigarette smoking (Löfroth et al., 1991). As a result, the impact of all these sources should be estimated and compared. These estimation of the source strengths can then be used in modeling studies of indoor air quality.

Table 6 listed a comparison of the emission factors of $PM_{2.5}$ found in environmental tobacco smoke (ETS), i.e. the number of cigarettes needed to produce the same amount of $PM_{2.5}$ emitted from the other indoor combustion activities (Daisey et al., 1998). In addition, incorporating the emission factors, ingredients weight and cigarette weight (0.55 g/cigarette, excluding the filter), the ETS equivalents for different cooking styles, burning incenses, mosquito coils, and candles and using combustion devices are derived. The result, as shown in Table 6, indicate that $PM_{2.5}$ released from Chinese style cooking would be equivalent to $PM_{2.5}$ mass released as ETS from burning 0.5 (deep frying pork chop) to 3 (stir frying pork chop) cigarettes. When compared to other indoor sources, cooking generally produce much less particles than incense burning, mosquito coil burning and other combustion devices. This may because cooking is capable to produce ultrafine particles which usually form the bulk of particle number but contribute only negligibly to particle mass. However, these fine particles have been linked to mortality and morbidity of human beings, and they have been found in several animal studies to be more toxic than larger particles of the same composition (Oberdoester et al., 1995).

Table 4-2-6 Comparison of emission factor and ETS equivalent value with different types of indoor combustion events for $PM_{2.5}$

Combustion events	Emission factor (mg/g)	Weight (g)	ETS equivalent
Cooking styles			
Deep Frying Pork Chop	0.008	400	0.5
Stir Frying Pork Chop	0.051	400	3
Incense burning			
Inc 1	99.7	0.99	14
Inc 2	62.4	1.37	13
Inc 3	41.5	6.04	37
Inc 4	71.8	1.86	20
Inc 5	104	2.21	34
Mosquito coils			
MC 1	28.9	2.49	11
MC 2	47.8	2.21	15
MC 3	20.3	2.37	7
MC 4	43.9	2.02	13
MC 5	21.5	2.02	6
Combustion devices			
Kerosene lamp	9.04	15.7	21
Oil lamp	7.32	15.7	17
Candles	0.87	15.2	2
ETS	12.4	0.55	/

Note * the cooking styles data are the one used in this study
* the incenses are chosen from (Lee and Wang, 2004);
* the mosquito coils are chosen from (Chen, 2004);
* the combustion devices data are chosen from (Fan and Zhang, 2001);
* ETS data were from (Daisy et al., 1998)

4.2.7 $PM_{2.5}$ emission rates from meat

According to the internal statistics data provided by Food and Environmental Hygiene Department, the personal consumption of meat (PCRmeat) in Hong Kong was approximately 25 kg/year. If we assume that all meat in Hong Kong was either deep fried or stir fried, based on the emission factor measured in this study, the range of annual $PM_{2.5}$ emission from meat ($ER_{PM2.5}$) can be estimated according to the following equations:

$$ER_{PM2.5}\ (kg/year) = Emission\ Factor\ (g/kg) * PCRmeat(kg/year) * n * 10^{-6}(kg/g)$$

Where n was the population in Hong Kong (7,000,000). This study yielded $ER_{PM2.5}$ fall in the range from 1512 kg/year to 8992 kg/year. HKEPD reported that a total of $2x10^3$ ton/year PM_{10} mass was emitted from vehicle sources in Hong Kong in the year 2004 (http://www.epd-asg.gov.hk/tc_chi/report/files/ea04c.pdf). Assume that 70% PM_{10} mass is composed of $PM_{2.5}$, this study shows $PM_{2.5}$ mass emitted from meat cooking contributes only about 0.1% ~ 0.6% of that from vehicular traffic sources.

It should be noted that the measurements of annual $PM_{2.5}$ emission rate for meat cooking in Hong Kong in this study are representative of deep frying and stir frying only. However, Hong Kong is a vibrant city famed for its great variety of food that represents the essence of local culture. The emissions from meat cooking would therefore fluctuate with the type of meat and cooking methods. Therefore the

estimated annual emission flux of $PM_{2.5}$ in the present study can only provide a general guide with a relatively high degree of uncertainty.

Chapter 5

Conclusion and Future Work

5. Conclusion and Future Work

5.1 Conclusion

The characterization of cooking fumes from both commercial restaurants and residential dwellings were investigated in this thesis. It acts as a pilot study in determination of emission profiles of emissions from commercial restaurants and residential dwellings in Hong Kong. Six commercial restaurants, including two Chinese restaurants, two western restaurants, two fast food restaurants and one common residential dwelling were selected for sampling and analysis. For commercial restaurants, samples were collected through each restaurant's exhaust ducts during peak hours. Over 80 organic compounds were identified and quantified in this study. For residential dwellings, different Chinese cooking methods were applied in the kitchen to evaluate the emission. According to the experiments' results, the following conclusions can be drawn:

1 On average, the concentrations of $PM_{2.5}$ in cooking fumes from commercial restaurants were roughly two or three orders of magnitude than the ambient concentration. Generally, the mass concentrations of $PM_{2.5}$ in western restaurants were much lower than that of in Chinese and Fast food restaurants. As far as the chemical compositions are concerned, e as expected. Elemental carbon was also measured in the fine particle emissions but the concentrations were low, it made up of about 0.9%~5.2% of the fine particle mass. Several ionic species also were

measured in the fine particle emissions at lower but noticeable percentages, for example, SO_4^{2-} was found to contribute 0.9% and 1.6% of the fine particle mass in both western restaurants.

2 Among the identified organic compounds, PAHs, alkanes, fatty acids and steroids were identified as major individual organic compounds.

2.1 Most PAHs are in gaseous phase in cooking fume exhaust. The fractions of gaseous PAHs in the six sampled restaurants were ranged from 80% to 100%. For gas phase PAHs, the distribution patterns in different types of restaurants were different. For particle phase PAHs, four-ring PAHs along with three-ring PAHs, account for nearly 60% of total measured particle phase PAHs while two-ring PAHs contributed much less.

2.2 Of the quantified organic mass, over 70% was fatty acid. Especially in fast food restaurants, fatty acids contribute nearly 90% of total particle phase organic compounds. Besides the normal alkanoic acids, three alkenoil acids, i.e., oleic (C18:1), linoleic (C18:2), and palmtoleic (C16:1) acids, were also abundant among all fatty acids measured. In general, fast food restaurants, whose main cooking style is deep frying, have the highest fatty acid emission.

2.3 Most alkanes are presented in gaseous phase in most sampled restaurants. Cooking is found to be a unique source of alkane, according to its distribution diagram. The CPI of the alkanes in all restaurant samples ranges from 1.38 to 2.63. These high CPIs measured in this study may

attribute to these organic matters.

3 According to a previous tunnel study conducted in Environmental Protection Department, (Final Report of Determination of Suspended Particulate & VOC Emission Profiles for Vehicle Sources in Hong Kong, http://www.epd.gov.hk/epd/english/environmentinhk/air/studyrpts), the emission rate of $PM_{2.5}$, gas and particle phase PAHs from commercial restaurants were approximately **17.9%**, **9.2%** and **18.3%** of that from vehicles. In addition, Chinese restaurant has the highest percentage of emission, over 80%, because of its largest number.

4 In residential dwellings, it is observed that deep frying and stir frying pork chops were capable to elevate the indoor particle number concentration by a factor of 8 and 48, respectively. In addition, indoor $PM_{2.5}$ mass concentrations showed an increase over the ambient level by 7 and 15 times during deep frying and stir frying. As far as particle size distributions are concerned, deep frying has a peak (6097 pt/ft^3) at 0.3 µm, and a second peak (4817 pt/ft^3) at 0.7µm, while stir frying has a peak (15976 pt/ft^3) at 1 µm, and a second peak (13917 pt/ft^3) at 0.7µm.

5 For $PM_{2.5}$ emissions, the mean emission rate of 6.91 mg hr^{-1} and 41.1 mg h^{-1} resulting from deep frying and stir frying pork chops were found in this study. For ultrafine particle number emissions, the average emission rate from stir frying was calculated to be $8.57x10^{13}$ pt/hr, which was nearly seven times higher than that from deep frying. When compared to other indoor sources, cooking generally produce much less particles than incense burning, mosquito coil burning and

other combustion devices.

In this thesis, a baseline database of cooking emissions profile and characteristics that are directly relevant to conditions in Hong Kong was established. This database will become a useful tool to understand and plan strategies to improve Hong Kong's air quality.

5.2 Future Work

To date, few measurements of different kinds of cooking emissions have been made, as cooking fume emission is often overlooked when compared with other sources such as power plants, industrial sources and vehicular sources. However, their potential impacts on atmosphere could not be neglect.

This work has conducted quantitative determination of the composition of cooking fumes in Hong Kong. However, future work can be done to understand more about cooking fume emissions.

1. This study has only provided insight into the fine particle emissions from commercial restaurants' cooking emissions, other pollutants, for example, VOCs, carbonyls… have not be investigated and quantified.
2. This study has revealed the general chemical compositions and characteristics of fine particles generated by restaurants in Hong Kong, which are useful in source appointment models, e,g., Chemical Mass Balance model (CMB), to estimate the contribution of cooking emissions to atmospheric fine particles. In further study, the source profiles, tracers and emission rates from various styles of cooking emissions need to be explored to evaluate detailed the contribution of this pollution source.
3. In this study, only two Chinese restaurants, two western restaurants and two fast food restaurants were selected for sampling. The samples are relatively limited and more samples should be collected from different kinds of restaurants.

4. In residential dwellings, more cooking tests can be carried out to create a emission profile for different ingredients.

Appendix

Appendix 1: SOP for PAHs Analysis

The Standard Operating Procedures (SOP) is a restricted document and is only used for internal purpose of Hong Kong Government Laboratory (HKGL). However, the quality management system implemented in the Analytical and Advisory Services Division of the HKGL is in full compliance with the ISO/IEC 17025. The SOP strictly adheres to the requirements as described in the said standard.

The relative expanded uncertainty for the 17 PAHs have been provided to EPD. A summary table is shown as follows:

PAHs	Relative Expanded Uncertainty (%)*
Naphthalene	± 58
Acenaphthylene	± 43
Acenaphthene	± 42
Fluorene	± 30
Phenathrene	± 19
Anthracene	± 23
Fluoranthene	± 21
Pyrene	± 19
Benz(*a*)anthracene	± 51
Chrysene	± 38
Benzo(*e*)pyrene	± 24
Benzo(*b*)fluoranthene	± 51
Benzo(*k*)fluoranthene	± 20
Benzo(*a*)pyrene	± 21
Dibenz(*a*,*h*)anthracene	± 35
Benzo(*g*,*h*,*i*)perylene	± 36
Indeno(1,2,3-*cd*)pyrene	± 25

Note: Coverage factor k = 2, with approximately 95% confidence level.

As for the QA/QC criteria, the method HKGL employed for the determination of PAH is an HOKLAS accredited method (method code: GL-OR-10) using HPLC-UV-FLD technique as agreed at the beginning of the Cooking Study project. Certified reference materials traceable to international standards were used during the analyses of every batch of samples.

Appendix 2: GC/MS Analysis of Solvent Extractable Organic Compounds in Atmospheric Aerosols

Scope and Application

This method describes the analysis of solvent-extractable organic compounds (SEOC) in atmospheric aerosols using GC/MS. The target compounds are listed in Table A1.

Summary of Method

This method is used for the determination of the above compounds in environmental samples. The filters are spiked with 250 μL each of HKIS#1, #2, and #3 (Table 1); this number should be recorded. They are then Soxhlet-extracted with a mixture of ~140 mL high purity dichloromethane and ~140 mL high purity methanol. The extract is reduced in volume to approximately 5 mL using a rotary evaporator and then filtered through glass wool to a test tube and rinsed with dichloromethane. To the extract 250 μL of high purity acetonitrile is added. [Acetonitrile serves to replace methanol upon further solvent evaporation to 250 μL. Methanol has to be replaced due to its reaction with silylation reagent BSTFA that is to be used for derivatizing –OH and –COOH containing compounds.] The samples are then blown down to 200 μL. The samples are then split into two equal portions of 100 μL and transferred to two Teflon-lid lined vials. One portion is used to analyze non-polar species (e.g., alkanes, PAHs, cycloalkanes, hopanes, steranes, and phthalates). The second portion is then silylated and analyzed by GC/MS within 18 hours. The first portion is stored to provide a second opportunity for a clean silylation reaction, if needed.

Materials and Apparatus

Reagents

1. Dichloromethane – high purity grade
2. Methanol – high purity grade

Both reagents 1 and 2 are redistilled at their boiling point before their use.

Standards

(1) Internal standard HKIS#1 contains tetracosane-D50 and Phe-D10.

(2) Internal standard HKIS#2 contains heptadecanoic acid (methyl-D3), phthalic acid (D4).

(3) Internal standard HKIS#3 contains levoglucosan-$U^{13}C6$.

(4) Injection internal standard #1 contains Chr-D12 and 1-PD.

(5) Injection internal standard #2 contains decanoic acid-D19.

(6) Spike Internal standard IS#4 (the same as IS#4 from UW, the concentrations of individual isotope-labeled standards are listed in Table A1-2).

(7) Parent standard mixtures including

HK-PSTD#1a Alkane/PAH mix 1, a subset of PMSTD#1 from UW + a few alkanes not included in PMSTD#1

HK-PSTD#1b Alkane/PAH mix 2, the same as PMSTD#2 from UW

HK-PSTD#2a Dicarboxylic acid /fatty acid mix, the same as PMSTD#3 from UW

HK-PSTD#2b Miscellaneous acid mix, the same as PMSTD#6 from

UW + a few fatty acids not included in PMSTD#2.

HK-PSTD#3a Fatty alcohol mix

HK-PSTD#3b Other-OH compound mix, the same as PMSTD#4 from UW

HK-PSTD#4 Biomass burning standard mix, the same as PMSTD#5

(Note: The compositions of HK-PSTD#1x-#4 are listed in Tables A2-1a, A2-1b, A2-2a, A2-2b, A2-3a, A2-3b, A2-4.)

(8) HKSTD #1: 1:2.5, 1:5, 1:10 dilutions, prepared from HK-PSTD#1a-1b.

(9) HKSTD #2: 1:2.5, 1:5, 1:10 dilutions, prepared from HK-PSTD#2a-2b, silylation step succeeds the dilution step.

(10) HKSTD #3: 1:5, 1:10, 1:40 dilutions, prepared from HK-PSTD#3a-3b, silylation step succeeds the dilution step.

(11) HKSTD #4: 1:2.5, 1:5, 1:10 dilutions, prepared from HK-PSTD#4, silylation step succeeds the dilution step.

Apparatus

(1) Microsyringes, 250 μL

(2) Rotary evaporator

(3) Thermal plate or oven for temperature-controlled heating at 70^{o}C.

(4) Boiling Flask, 500 mL, muffled at 550°F for 8 hours.

(5) Tongs

(6) Transfer pipets, muffled at 550°F for 8 hours.

(7) 3 mL Centrifuge Tubes, calibrated for 250 μL, muffled at 550°F for 8 hours.

(8) Nitrogen blow-down apparatus

(9) Analytical balance

(10) Amber Hi rec screw vial, Agilent, muffled at 550°F for 8 hours.

(11) Screw Cap red, Agilent

(12) Quartz fiber filters

(13) Glass wool, extracted with 50/50 solution of acetone and hexane, and muffled

(14) Pyrex test tubes (16x125 mm), muffled at 550°F for 8 hours and caps.

(15) Spatula

(16) 10 mL volumetric flasks

(17) 1 mL volumetric pipets

(18) 2 mL volumetric pipets

(19) 5 mL volumetric pipets

(20) Heating mantles for 500 ml boiling flasks

(21) Soxhlet extractors and condensers

(22) 1 mL and 5 mL heavy walled conical vials, Alltech.

Quality Control

(1) Prior to any standard or sample analysis, GC maintenance is done. This requires trimming the column, replacing the septa and liner, and inlet maintenance.

(2) A blank is run, followed by a HKSTD #1 1:10. The coronene peak should be extracted and must have 10,000 area counts and must be a minimum of 25% of the pyrene peak.

(3) With each batch of samples run, a blank and spike must be run prior to the samples.

(4) During the sample run, a 1:10 and a 1:5 dilution of the HKSTD#1 standard must be run approximately every ten samples.

(5) While analyzing the samples, any problems with the internal standard peaks should be flagged. These problems include area counts not proportional to the area counts of previously run samples.

(6) Problems with the compounds of interest should also be flagged. These problems include high baselines, which make peaks difficult to integrate and identify.

Extraction of filter substrate

(1) Prior to extraction, 20 μL HKIS#1, 20 μL of HKIS#2, and 20 μL of HKIS#3 are added to each sample.

(2) Extract each sample with a mixture of ~ 140 mL high purity dichloromethane and ~140 mL high purity methanol with a Soxhlet extractor for 14 hours.

(3) Reduce the combined extract to ~ 5 mL using a rotary evaporator.

(4) The concentrated extract is transferred and filtered through glass wool into a 5 mL heavy-walled, conical vial.

(5) Add 250 μL high purity acetonitrile in to the extract.

(6) The ~ 5 mL extract is then blown down to ~200 μL using a stream of N2.

(7) Use a 250 μL syringe to measure the volume of the extract in step (6) and record the volume.

Split and silylation of the filter extracts

(1) Split the sample into two equal portions, one portion stored in a 1mL micro V vial and the second portion transferred to a separate 1.0 mL V-vial.

(2) To the first micro V vial, add 25 μL injection IS#1 (chryene-D12 and 1-PD) for non-polar species determination. This portion is then ready for GC/MS injection.

(3) Add 40 μL of silylation grade pyridine into the second micro V vial for silylation.

(4) Spike 10 μL injection IS#2 (decanoic acid-D19, internal standard solution).

(5) Add 50 μL of bis(trimethylethylsilyl) trifloroacetamide (BSTFA) plus 1% trimethylchlorosilane (TMCS).

(6) Seal the vial and place it in an oven at 70^{o}C for 3 hours.

(7) Add 50 μL of injection IS#1 after cooling.

(8) Silylated samples are analyzed by GC/MS within 18 hrs.

Preparation of spike samples

(1) For each batch of samples to be processed, prepare a spike sample by spiking 200 μL of UW-IS#4 (1: 20 dilution, see Table A1-2) onto a blank pre-baked filter and a spike reference sample. The spike sample is treated the same way as aerosol samples. The spike reference sample does not go through the soxhlet extraction and volume reduction steps. The spike sample and the spike reference sample are used to assess recovery for each batch of samples.

(2) Spike reference sample for the non-polar analytes (SR-NP): transfer 100 μL of UW-IS#4 (1:20 dilution) to a 1 mL micro V vial, add 25 μL injection IS#1 (chryene-D12 and 1-PD) to the same vial. This sample is ready for GC/MS injection.

(3) Spike reference sample for the polar analytes (SR-P): transfer 100 μL of UW-IS#4 (1:20 dilution) to a 1 mL micro V vial; add 40 μL of silylation grade pyridine into the same micro V vial for silylation; spike 10 μL injection IS#2 (decanoic acid-D19, internal standard solution); add 50 μL of BSTFA + 1% TMCS; seal the vial and place it in an oven at 70^{o}C for 3 hours; Add 50 μL of injection IS#1 after cooling; analyze by GC/MS within 18 hrs.

(4) Spike sample for the non-polar analytes (S-NP) and for the polar analyes (S-P): Spike 100 μL of UW-IS#4 (1:20 dilution) to a blank filter. Process this spike sample the same way as the aerosol samples.

Method Calibration

(1) Inject four standards (HKSTD#1-#4) with three dilutions each, a total of 12 vials, listed above under standards section.
(2) Using these standards, a three-point plot is created for each compound of interest in the standards.
(3) A correlation coefficient of 0.990 or greater verifies the acceptability of the curve.

Internal standard preparation

Table 1 lists the type of internal standards, the concentration levels of stock solutions, and the amount of each stock solution that is to be spiked into each sample.

Table 1. Preparation of spike and injection standards

label	IS name	stock concentration (ng/uL)	amount spiked to samples

HKIS#1	$C_{24}D_{50}$	25 ng/uL	20 uL
	Phe-D10	5 ng/uL	20 uL
HKIS#2	$CD_3(CH_2)_{14}COOH$	60 ng/uL	20 uL
	Phthalic acid-D4	25 ng/uL	20 uL
HKIS#3	Levoglucosan-13C	1540 ng/uL	10 uL
UW-IS#4	See Table A1-1	1:20 dilution of UW-IS#4 master standard	200 uL
Injection IS#1	1-PD	25 ng/uL	25 ul: non polar fraction
	Chr-D12	5 ng/uL	50 ul: polar fraction [a]
Injection IS#2	$C_9D_{19}COOH$	60 ng/uL	10 uL [b]

[a] Note that injection IS #1 is added to samples before GC/MS injection, NOT to the filter.

[b] Note that injection IS#2 is added to the polar fraction before silylation step, NOT to the filter.

Standard Preparation

(1) Stock standard mixes are first prepared from single standards in batches and stored in 2-mL brown ampoules. They include

HK-PSTD#1a Alkane/PAH mix 1, a subset of PMSTD#1 from UW + a few alkanes not included in PMSTD#1,

HK-PSTD#1b Alkane/PAH mix 2, the same as PMSTD#2 from UW

HK-PSTD#2a Dicarboxylic acid /fatty acid mix, the same as PMSTD#3 from UW

HK-PSTD#2b Pimaric acid + a few fatty acids not included in UW standards

HK-PSTD#3a Fatty alcohol mix,

HK-PSTD#3b Other-OH compound mix, the same as PMSTD#4 from UW

HK-PSTD#4 Biomass burning standard mix, the same as PMSTD#5

(2) Three dilutions of HKSTD#1 are prepared from stock standard mixes of HK-PSTD#1a and HK-PSTD#1b according to Table 2. The quantification standards of HKSTD#1 include alkanes, PAHs, phthalates, and miscellaneous neutral compounds. They are ready for GC/MS injection.

Table 2: Summary of Preparation of Quantification Standard HKSTD#1

dilution	V of HKIS#1 (uL)	V of HK-PSTD#1a (uL)	V of HK-PSTD#1b (uL)	make-up vol (uL)	final V (mL)
1:2.5	100	400	400	100	1
1:5	100	200	200	500	1
1:10	100	100	100	700	1

(3) Three dilutions of HKSTD#2 are prepared from stock standard mixes of dicarboxylic acids, fatty acids, and miscellaneous acids according to Table 3.

The diluted standards then undergo silylation as described below and are analyzed within 18 hrs after silylation.

Table 3: Summary of Preparation of Quantification Standard HKSTD#2

dilution	V of HKIS#2 (uL)	V of HK-PSTD#2a (uL)	V of HK-PSTD#2b (uL)	make-up vol (uL)	final V (mL)
1:2.5	100	400	400	100	1
1:5	100	200	200	500	1
1:10	100	100	100	700	1

a. Transfer 100 μL of each quantification standard into separate 1 mL micro V-vials.
b. Add 40 μL of silylation grade pyridine into the micro V vial for silylation.
c. Spike 10 μL injection IS#2 (decanoic acid-D19).
d. Add 50 μL of BSTFA plus 1% TMCS.
e. Seal the vial and place it in an oven at 70^{o}C for 3 hours.
f. Add 50 μL of injection IS#1 after cooling.
g. Silylated samples are analyzed by GC/MS within 18 hrs.

Note: The quantification standards in Table 3 are diluted by 2.5 times after the silylation step.

(4) Three dilutions of HKSTD#3 are prepared in 1-mL vials from stock standard mixes of HK-PSTD#3a and HK-PSTD#3b according to Table 4. This set of standards contains fatty alcohols and other –OH containing compounds. The diluted standards then undergo silylation as described below and are analyzed within 18 hrs after silylation.

Table 4: Summary of Preparation of Quantification Standard HKSTD#3

dilution	V of HKIS#3 (uL)	V of HK-PSTD3a (uL)	V of HK-PSTD3b (uL)	make-up V (uL)	final V (mL)
1:5	100	200	200	500	1
1:10	100	100	100	700	1
1:40	100	25	25	850	1

a. Transfer 100 μL of each quantification standard into separate 1 mL micro V-vials.

b. Add 40 μL of silylation grade pyridine into the micro V vial for silylation.

c. Spike 10 μL injection IS#2 (decanoic acid-D19).

d. Add 50 μL of BSTFA plus 1% TMCS.

e. Seal the vial and place it in an oven at 70^{o}C for 3 hours.

f. Add 50 μL of injection IS#1 after cooling.

g. Silylated samples are analyzed by GC/MS within 18 hrs.

Note: The quantification standards in Table 4 are diluted by 2.5 times after the silylation step.

(5) Three dilutions of HKSTD#4 are prepared in 1-mL vials from HK-PSTD#4 according to Table 5. This standard contains a range of compounds related to biomass burning aerosols. The diluted standards then undergo silylation as described below and are analyzed within 18 hrs after silylation.

Table 5. Summary of Preparation of Quantification Standard HKSTD#4

Dilution	V of HKIS#3 (uL)	V of HK-PSTD#4 (uL)	make-up vol uL)	final V (mL)
1:2.5	100	500	400	1
1:5	100	200	700	1
1:10	100	100	800	1

a. Transfer 100 μL of each quantification standard into separate 1 mL micro V-vials.

b. Add 40 μL of silylation grade pyridine into the micro V vial for silylation.

c. Spike 10 μL injection IS#2 (decanoic acid-D19).

d. Add 50 μL of BSTFA plus 1% TMCS.

e. Seal the vial and place it in an oven at 70^{o}C for 3 hours.

f. Add 50 μL of injection IS#1 after cooling.

g. Silylated samples are analyzed by GC/MS within 18 hrs.

Note: The quantification standards in Table 5 are diluted by 2.5 times after the silylation step.

Sample injection

A. Inject the four sets of standard mixes with three dilutions each, a total of 12 vials.

B. Following the standards, inject a blank, the spike sample, and the samples.

C. After the initial 12 standards have been injected, every tenth vial should be a HKSTD #1 1:10 check standard followed by HKSTD#1 1:5 standard and then the next ten samples.

D. When all of the samples have been entered, inject all the three HKSTD#1 again. [Note: No need to inject HKSTD#2, #3 and #4 again.]

a. Analysis – Chromatography

A. A calibration table is created for the standard compounds.

B. The estimated retention times of the compounds denoted * are found using Calculation A.

C. Obtain peak areas of the specified target ions in each sample, including the blank, the check standards, and the spike samples.

D. Percent recoveries are calculated using the spike sample.

E. Paper and electronic reports are generated for every sample.

F. When analysis is completed, copy the method files, data files, and the results to a CD for record.

b. Calculations

A. Retention time for new *'d compounds

RT = RT from *'d cmpd from old method x RT from cmpd in std from new method

RT from cmpd in standard from old method

This needs to be evaluated according to our own experience.

B. Percent Recovery

$$\%recovery = \frac{(\frac{PA_{spike\ analyte}}{PA_{injection\ IS}})_{spike\ sample}}{(\frac{PA_{spike\ analyte}}{PA_{injection\ IS}})_{spike\ reference\ sample}} \times 100\%$$

Data management

Data is collected utilizing HP Chemstation software and transferred to the laboratory

worksheet. All data, including calibration standards and samples, is reviewed (by peers or supervisor) and then copied to a CD.

Table A1-1 Target Compounds (Continued)

PAHs	**Fatty alcohols**	**Miscellaneous –OH containing compounds**	**Others**	
Fluoranthene	1-undecanol	Levoglucosan	Acetosyringone	
Acephenanthrylene	1-dodecanol	Cholesterol	Coniferyl Aldehyde	
Pyrene	1-tridecanol	b-sitosterol	Acetonylsyringol	
Benzo(A)Anthracene	1-tetradecanol	Ergosterol	Sinapic Aldehyde	
Chrysene	1-pentdecanol	Stigmasterol	Propenyl Syringol	
Benzo(B)Fluoranthene	1-hexadecanol	Monopalmitin (16:0)	1H-Phenalen-1-One	
Benzo(K)Fluoranthene	1-octadecanol	Monoolein (18:1)	Anthroquinone	
Benzo(J)Fluoranthene	1-eicosanol	Monostearin (18:0)	1,8 - Naphthalic Anhydride	
Benzo(E)Pyrene	1-docosanol	glycerine	Retene	
Benzo(A)Pyrene	1-tricosanol		Squalene	
Perylene	1-hexacosanol		Syringealdehyde	
Indeno(Cd)Pyrene	1-heptacosanol		Propionylsyringol	
Dibenz(Ah)Anthracene	1-octacosanol		Butyrylsyringol	
Benzo(Ghi)Perylene	1-triacontanol			
Coronene				
Benzo(Ghi)Fluoranthene				
Cyclopenta(Cd)Pyrene				
Benz(De)Anthracen-7-One				
Methyl Mw 226 PAH				
Benz(A)Anthracene-7,12-Dione				
Methyl Chrysene (Methyl Mw 228 PAH)				
Methyl Fluoranthene (Methyl Mw 202 PAH)				

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