CONCENTRATION COMPARISON OF THE INDOOR AIR POLLUTANTS IDENTIFIED FROM THE RESTAURANTS WITH THE DIFFERENT COOKING AND VENTILATION METHODS

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ABSTRACT

This study compared the concentrations of indoor air pollutants identified from the 5 restaurants including a category A (two Korean barbecue houses) during a lunch time period and a category B (one Japanese, one Chinese, and one Italian restaurants) during a dinner time period. This study analyzed the indoor (at breathing zones) and outdoor concentrations of the air pollutants, including particulate matter (PM) and formaldehyde (HCHO), and aldehydes, before and during eating meals.

The average concentrations of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ measured at the breathing zones during eating period at a Korean barbecue house using charcoal as cooking fuel were 169, 124, and 63 $\mu g/m^3$, respectively. The average ratios for $PM_{1.0}/PM_{10}$, $PM_{2.5}/PM_{10}$, and $PM_{1.0}/PM_{2.5}$ at the barbecue house during the eating period were 0.38, 0.73, and 0.52, respectively. However, the average ratios of them at other restaurants during their eating periods were 0.10 – 0.26, 0.32 – 0.45, and 0.29 – 0.58, respectively. The Chinese restaurant showed the second highest $PM_{2.5}$ and PM_{10} concentrations. The formaldehyde concentrations in the investigated restaurants ranged from 68.7 to 264.8 ppb (89.7 to 345.9 $\mu g/m^3$). The highest formaldehyde and the total aldehyde levels were observed in the Japanese restaurant. This may be because of aldehydes emitted from frying processes of fish and other seafood with oils and of corns and other vegetables with cheese and mayonnaise in the Japanese restaurant. Room volume or people occupancy of the restaurants might not significantly affect the PM and HCHO levels at the breathing zone.

KEYWORDS

Indoor, Cooking, Restaurant

MATERIALS AND METHODS

This study analyzed the concentrations of indoor air pollutants such as particulate matter (PM) and aldehydes identified from the different types of restaurants, located in an urban area, Ulsan, in Korea. This study have selected 5 restaurants have different cooking styles with different major materials and also different ventilation methods or situations. The selected restaurants were classified as two

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groups: a category A (two Korean barbecue houses) during a lunch time period and a category B (one Japanese, one Chinese, and one Italian restaurants) during a dinner time period. Indoor air samples at each restaurant were collected at breathing zones of the people who participated in cooking and eating Korean barbecues on the tables with sitting on the room floor in the category A restaurants. The indoor air samples were collected during eating the foods cooked from their kitchens in the category B restaurants. The participants were sitting on the room floor from Japanese and Chinese restaurants, however, they were sitting on the chair sharing their big eating room (restaurant) space with other people in the Italian restaurant. This study also collected the indoor air samples at the study places before cooking the Korean barbecues or eating the food in the study restaurants. Outdoor air samples were conducted at the outsides that might not be affected by the indoor exhaust of the restaurants during 2 hours before starting the indoor air samplings. Real time concentrations of PM and formaldehyde were obtained during the measurement periods. The portable PM monitors (GT-331, Sibata), which can simultaneously measure particle sizes of $PM_{1.0}$, $PM_{2.5}$, $PM_{7.0}$, PM_{10} and total suspended particulate (TSP) using a light scattering method and then convert their mass concentration (μg/m^3) every 5 min, were used for the real time PM concentrations. The real time concentrations of formaldehyde were obtained using portable formaldehyde monitors (Z-300XP, Environmental Sensors Co.). Air samples for aldehyde measurement were collected with 2,4-dinitrophenyl hydrazine (2,4-DNPH) tubes (Supleco Co.) using a personal air sampling pumps with a flow rate of 0.5 ml/min. The collected aldehydes in the tubes react with 2,4-DNPH producing 2,4-DNPH-aldehyde derivatives. The chemical analysis of the DNPH-aldehyde derivatives (hydrazones) extracted by acetonitrile were performed using a high performance liquid chromatography (HPLC) equipped with a ultra-violet detector.

RESULTS AND DISCUSSION

PM Concentration of Korean Barbecue Restaurants

Figures 1 and 2 show size distribution of particular matter (PM) as a function of time, including before, during and after cooking periods of a seasoned meat, inside the room in a Korean barbecue house. The barbecue house used liquefied pressurized gas (LPG) as heat source and cooking plate made of stainless steel for the meat cooking. The average concentrations of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} before the side dish is served or the meat is cooked on the cooking plate were 4.5, 7.2 and 12.6 ug/m^3, respectively. As the side dish is served on the dinning table and the cooking plate is heated using LPG flame, the PM concentrations increased approximately 2 times. As the meat cooking got started on the heated cooking plate, the PM concentrations sharply increased. The average concentrations of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} during cooking the sliced meat and eating the barbecued meat were 18.2, 32.0 and 71.1 ug/m^3, respectively. The increased concentrations of PMs ($PM_{1.0}$, $PM_{2.5}$, $PM_{7.0}$, PM_{10}, and TSP) were ranged from 4.0 to 6.6 times, depending upon particle size, as compared their concentrations before the cooking the meat or serving the side dish. After the first cooking the meat which was a main course, the PM concentrations sharply decreased. This indicates the meat cooking greatly increased the PM concentrations at the breathing zones of the people, who stayed in the barbecue room, resulting in high personal exposure to PMs even during the short period of cooking time. As the second cooking, which used a smaller amount of the meat as compared the first cooking, was begun eating rice with soup, the PM concentrations increased again. However, the increases in the PM concentrations were not that high as compared those at the first cooking. This represents the increase of the amount of the meat barbecued using the cooking method can highly increase PM concentrations in the barbecue room. Even after completing the second cooking and eating rice, the PM concentrations were still approximately 2 times as high as those before the first cooking and serving the side dishes. This represents the PMs produced from mainly cooking the meat were not completely removed or deposited in the room even after completing the second cooking and eating rice.

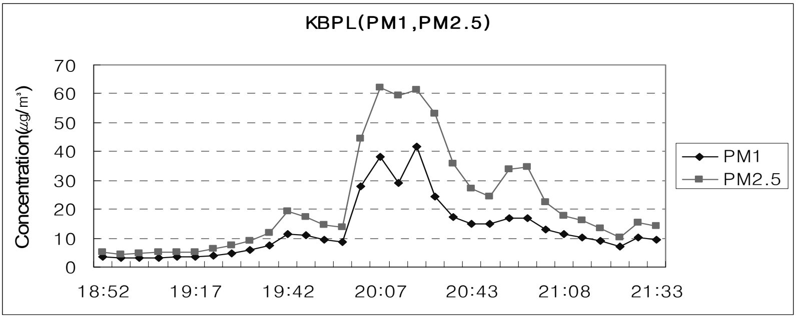


Figure 1. $PM_{1.0}$ and $PM_{2.5}$ concentrations at the Korean barbecue house using plate and LPG flame

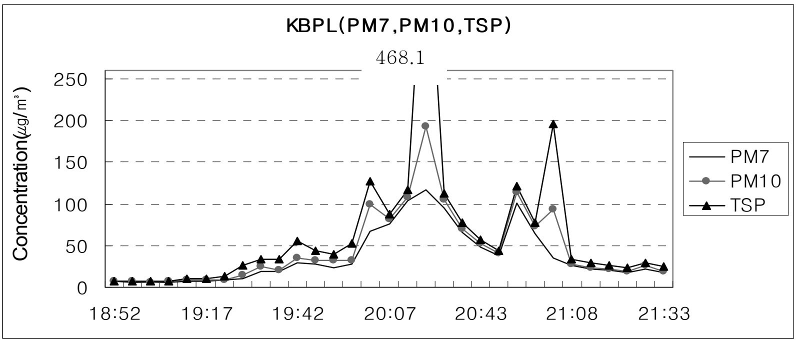


Figure 2. $PM_{7.0}$, PM_{10}, and TSP concentrations at the Korean barbecue house using plate and LPG flame

Figures 3 and 4 show size distribution of particular matter (PM) as a function of time, including before, during and after cooking periods of a seasoned meat, inside the room in another Korean barbecue house. The barbecue house used charcoal as heat source and cooking grid made of stainless steel wire for the meat cooking. The average concentrations of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} before the side dish is served or the meat is barbecued on the barbecue wire using charcoal flame were 9.1, 13.7 and 20.7 ug/m^3, respectively. These concentrations were approximately 2 times high as compared those in the barbecue room before cooking meat using LPG flame and the barbecue plates. There were some meat cooking activities by other customers at the outside of the study room in the restaurants. Therefore, the high PM concentrations were probably caused by infiltration effects of the PMs or fumes, generated from meat cooking by other customers at the outside of the study room, into the study barbecue room. However, the cooking activities at outside of the study room in barbecuing meat, using the barbecue plates and LPG flame, were not active. Therefore, the similar infiltration effects might not be significant. As the meat cooking got started on the heated barbecue wire, the PM concentrations sharply increased. The average concentrations of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} during cooking the sliced meat and eating the barbecued meat were 63.7, 124.1 and 169.4 ug/m^3, respectively. These PM concentrations were much higher, ranging from 2.4 (PM_{10}) to 3.9 ($PM_{1.0}$), as compared those in barbecuing meat using the barbecue plates and LPG flame. These high PM concentrations were because of the incomplete burning the liquids dropped onto the charcoal flame (explained in detail in the next paragraph).

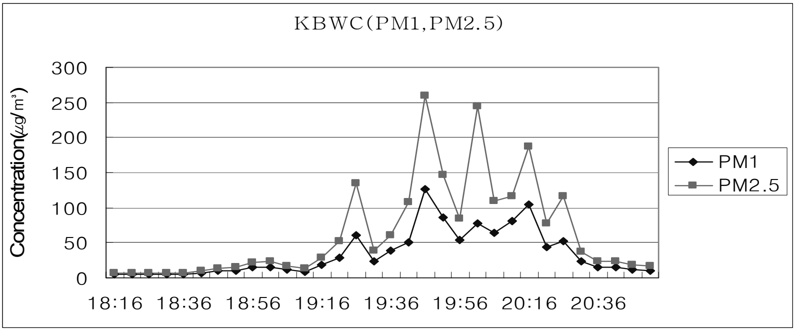


Figure 3. $PM_{1.0}$ and $PM_{2.5}$ concentrations at the Korean barbecue house using wire grid and charcoal flame

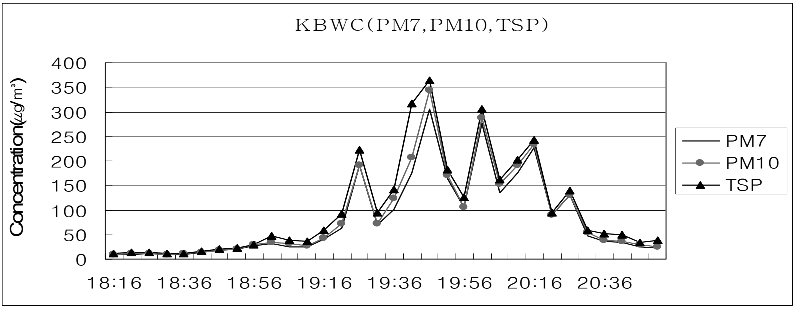


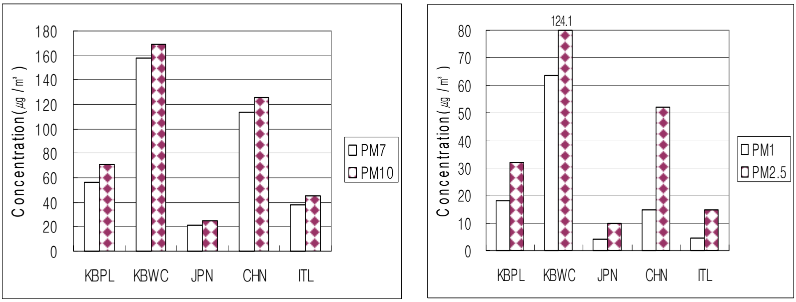
Figure 4. $PM_{7.0}$, PM_{10}, and TSP concentrations at the Korean barbecue house using wire grid and charcoal flame

Figures 3 and 4 also show a repeating pattern of increase and decrease in the concentrations of the PMs produced during barbecuing meat using heated wire grid on charcoal flame. The PM concentrations increased because of cooking fumes or particulates from the meat cooking. The sharp increase of in the PM concentrations is caused by dropping of the water and liquid droplets contained in the prepared meat onto the charcoal flame. Also, fatty acids and liquids produced from meat barbecuing on the hot wire grid dropped onto the charcoal flame. The dropped liquids including water and fatty acids were burned onto the charcoal flame. However, the dropped liquids blocked the oxygen supply required for complete burning of the materials, resulting in incomplete burning. The incomplete burning or combustion of the liquids can greatly contribute to the sharp increase in the PM concentrations. The PM concentration levels is sharply reduced after the meat is cooked on the wire and the incomplete burning is gone. However, the increase and decrease phenomena are repeated with barbecuing of another prepared fresh meat.

In addition, the increased concentrations of PMs ($PM_{1.0}$, $PM_{2.5}$, $PM_{7.0}$, PM_{10}, and TSP) were ranged from 7.0 to 9.1 times, depending upon particle size, as compared their concentrations before the cooking the meat or serving the side dish. After completing cooking meat and eating rice, the PM concentrations were still approximately 1.6 – 1.8 times as high as those before the cooking and serving the side dishes at first. This also represents the PMs produced from meat cooking were still remained in the room even after completing cooking meat and eating rice. This also indicates the sufficient ventilation after cooking the meat should be provided for less exposure of the people to the PMs in the barbecue room.

Comparison of PM Levels of 5 Restaurants

Figure 5 shows average concentrations of $PM_{1.0}$, $PM_{2.5}$, $PM_{7.0}$, and PM_{10} at breathing zones of the people during eating food at the 5 different restaurants. The highest PM concentrations observed at the Korean barbecue house, using wire grid and charcoal flame, followed by the Chinese restaurant that usually uses a lot of oil during cooking food. The highest PM concentrations at the Korean barbecue house was due to cooking fumes of meat from on the wire grid and incomplete burning of the liquids dropped onto the charcoal flame. The high PM concentrations at Chinese were caused by emissions from the food that was used a lot of cooking oils, such as corn oil or sesame oil, used for cooking meat and vegetables. The concentrations of PM_7 and PM_{10} at the inside room before delivery of the cooked Chinese food into the study room were much higher than those at other restaurants. This is because of the infiltrated cooking fumes or PMs from the neighboring rooms, which had early delivered cooked food, into the study room. However, the concentrations of $PM_{1.0}$ and $PM_{2.5}$ at that time were similar to other restaurants. This represents the cooked Chinese food have a more contribution to increasing in concentration of coarse particles rather than fine particles. The lowest average concentrations of the PMs were observed at the Japanese restaurant followed by the Italian one.



Note: KBPL= Korean barbecue using plate and LPG, KBWC= Korean barbecue using wire grid and charcoal, JPN=Japanese restaurant, CHN= Chinese restaurant, ITL= Italian restaurant

Figure 5. Average PM levels at the 5 types of restaurants during cooking meat or eating food

Thus there was slight increase, 12 - 56 %, in the PM concentrations during eating the Japanese food as compared before the eating. One main reason of the lowest PM concentrations observed at the Japanese restaurant is because the main dish was eating raw fish in stead of cooked food. This indicates cooking or eating activities, including barbecuing meat using charcoal flame or LPG flame, incomplete burning the liquids on the charcoal flame, and eating cooked food, in rooms of restaurants can greatly increase personal exposure levels to the PMs during mealtimes.

PM ratios to PM_{10} concentration

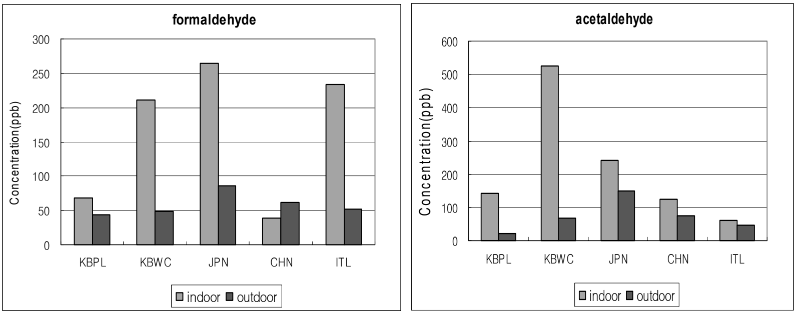
Table 1 shows PM concentration ratios to their PM_{10} concentrations at the 5 different restaurants. The average ratios for $PM_{1.0}/PM_{10}$, $PM_{2.5}/PM_{10}$, and $PM_{1.0}/PM_{2.5}$ at the Korean barbecue house, using grid wire and charcoal flame, during the period of barbecuing meat and eating the cooked meat were 0.38, 0.73, and 0.51, respectively. The ratios at the Korean barbecue house, using plate and LPG flame, during the barbecuing and eating period were 0.42, 0.63, and 0.57, respectively. However, the average ratios of them at other restaurants during their eating periods were 0.10 – 0.17, 0.32 – 0.41, and 0.28 – 0.43, respectively. The Korean barbecue houses have much higher fractions of fine particles than other Japanese, Chinese, and Italian restaurants. In particular, the Korean barbecue house using grid wire and charcoal flame showed a higher fine particle fraction. Even though the Chinese restaurant showed the second highest $PM_{2.5}$ concentrations, its fine particle fraction was relatively low. This is because of its very high PM_{10} concentration that has a higher fraction of coarse particles.

Table 1. PM concentration ratios to their PM_{10} concentrations at the 5 restaurants

Restaurant type	Korean Barbecue				Japanese		Chinese		Italian	
	Plate + LPG		Wire + Charcoal							
PM ratio	Before	During	Before	During	Before	During	Before	During	Before	During
PM1/PM10	0.26	0.42	0.44	0.38	0.12	0.17	0.04	0.12	0.04	0.1
PM2.5/PM10	0.45	0.63	0.66	0.73	0.31	0.39	0.20	0.41	0.1	0.32
PM7/PM10	0.79	0.91	0.93	0.93	0.83	0.83	0.78	0.90	0.73	0.83
PM10/PM10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
TSP/PM10	1.44	1.21	1.2	1.13	1.36	1.4	1.49	1.12	1.44	1.9

Comparison of Aldehyde Levels of 5 Restaurants

Figure 6 shows average concentrations of formaldehyde and acetaldehyde measured at breathing zones of the people during eating food at the 5 different restaurants. The highest average concentrations of the formaldehyde were observed at the Japanese restaurant followed by the Italian restaurant and the Korean barbecue house using wire grid and charcoal flame in order. Their ratios of indoor concentration to outdoor concentrations of formaldehyde ranged from 3.1 to 4.6. However, the highest average concentrations of the acetaldehyde were observed at the Korean barbecue house, using wire grid and charcoal flame, followed by the Japanese one. The highest average concentrations of the acrolein + acetone and butyaldehyde were observed at the Japanese restaurant. However, the highest average concentrations of the propionaldehyde were observed at the Korean barbecue house using plate and LPG flame. The highest formaldehyde and the total aldehyde levels were observed in the Japanese restaurant. This may be because of aldehydes emitted from frying processes of fish and other seafood with oils and of corns and other vegetables with cheese and mayonnaise in the Japanese restaurant. Room volume or people occupancy of the restaurants might not significantly affect the PM and HCHO levels at the breathing zone.



Note: KBPL= Korean barbecue using plate and LPG, KBWC= Korean barbecue using wire grid and charcoal, JPN=Japanese restaurant, CHN= Chinese restaurant, ITL= Italian restaurant

Figure 6. PM concentrations at the 5 types of restaurants

CONCLUSIONS

In a comparison study on the levels of PMs ($PM_{1.0}$, $PM_{2.5}$, $PM_{7.0}$, PM_{10}, and TSP) and aldehydes at the breathing zones of the people during barbecuing meat and eating food in the 5 restaurants, one Korean barbecue house using wire grid and charcoal flame showed the highest PM concentrations followed by the Chinese restaurant. The high PM concentrations in the barbecue house are caused by cooking fumes of meat and incomplete combustion of the liquids dropped onto the charcoal flame. Two Korean barbecue houses showed higher fine fractions of particles than other restaurants. The cooking food using cooking oil in the Chinese restaurant greatly contributed to the high personal exposure to PMs. The highest personal exposure to formaldehyde was identified in the Japanese restaurant followed by the Italian restaurant.

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