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A REVIEW ON AERODYNAMIC SIZES AND CONCENTRATION OF PARTICULATE MATTER EMITTED FROM VARIOUS COOKING STYLES IN DIFFERENT HOUSEHOLDS

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Abstract
This review seeks to find whether there is a correlation between the concentration of particulate matter and the cooking method. The study used various cooking techniques as employed in different households. Therefore, it has been noted that PM generated from roasting, grilling, and frying of food shows a high concentration of particulates. Multipath Particle Deposition (MPPD Ver. 3.04) model has been found to offer an alternative, affordable and fast method of understanding the deposition characteristics of particulate matter in the human respiratory tract. Generally, the profiling of particulate matter sizes and their concentrations have shown a strong relationship between the cooking method and particulate matter concentrations. This review, therefore, recommends methods such as boiling and steaming for cooking as opposed to deep-frying, stir-frying, grilling and roasting, which are commonly adopted by fast food hotels/ restaurants worldwide. Also, the use of a well-ventilated kitchen and fast particulate clearing hoods is much encouraged to avoid overexposure to this PM.

Key terms: Cooking styles, morphology, particulate matter, pollution.

1.0 INTRODUCTION

Environmental pollution, either indoor or outdoor, lead to human exposure to particulate matter, among others. Indoor air quality is a key parameter to healthy living by the human race. With the exponential increase in population, quality housing has been a great challenge for most people. Most of the world's population live in poor housing conditions, which affect their comfort and affect their health as a whole with reference to poor ventilation (Cheung & Jim, 2019). Indoor environment pollution is associated with various pollutants ranging from indoor building materials and household goods, indoor activities such as cooking, cleaning and the introduction of polluted outdoor air (Cocârţă et al., 2021; Gonzalez-Martin et al., 2021; Jodeh et al., 2018; Wang & Jia, 2021; Bang et al., 2018; Kang & Choi, 2015; Um et al., 2019). According to World Health Organization (WHO), a global conference on air pollution and health held in Geneva in 2018 reported that over 91 per cent of the world population lives in conditions where the air quality exceeds the recommended limits (World Health Organization, 2021). In addition, cooking styles have been seen to contribute to indoor pollution (Alves et al., 2021; Bandowe et al., 2021; Ma et al., 2021; Nsamba et al., 2021; Wang et al., 2018). For instance, meat roasting, a common practice in most traditional African communities, has been seen to generate PM10 and PM2.5 particulates (Balasubramanian et al., 2021; Gysel et al., 2018; Joo & Ji, 2020).

Retention of inhaled particulate matter in human lungs is an essential indicator of respiratory health risks (De Grove et al., 2018). However, the epidemiological studies on inhalation and clearance of particulate matter cannot be achieved through experimental means easily (Protano et al., 2017). Therefore, mechanistic computational software based on physical and physiological parameters that mimic particulate transport in the respiratory system accurately is used (Asgharian, Owen, Kuempel, & Jarabek, 2018). Multiple-path particle deposition (MPPD) Model version 3.04 is one of the most robust models advanced in respiratory studies (Manojkumar et al., 2019).

2.0 LITERATURE REVIEW

Particulate Matter may be defined as air aerosols that comprise solids and liquid droplets suspended in the atmosphere. PM is grouped into three levels based on its aerodynamic diameter: coarse particles (PM2.5–10) with a diameter of 2.5–10 μm, fine particles (PM2.5) with a diameter equal or less than 2.5 μm, and ultrafine particles with a diameter less than 0.1 μm (Gysel et al., 2018; Li & Liu, 2021). All the particulates are inhalable and can find their way deep into the respiratory system. (Gysel et al., 2018) previous documentation indicates that PM2.5 is ultrafine and has more gracious consequences than PM10 since they have high infiltration power deep down in the lungs as well as alveolar covering (D'Amato et al., 2016; Holm et al., 2021; Hsiao et al., 2022; World Health Organization, 2021; Popa et al., 2021; Zhu et al., 2021). The examination has demonstrated that PM10 or PM2.5 can live in the lungs, result in gentle to extreme sickness, and cause genuine ailments and dangerous diseases (Terzano et al., 2010; Chen et al., 2018; Hsiao et al., 2022). Additionally, inhaling PM2.5 and the chemicals bound to it, such as quinones and heavy metals, can trigger the reactive oxygen species (ROS) overproduction, which counteracts anti-oxidative defences (Gao et al., 2020; Niu et al., 2020; Riggs et al., 2020; Xu et al., 2020).

(Gao et al., 2020; Niu et al., 2020; Riggs et al., 2020; Xu et al., 2020). The presence of increased ROS imbalance can cause oxidative stress, inflammatory response, DNA and cell damage, which is the basis for several diseases (Kelly, 2003; Bitterle et al., 2006). Transition metals, secondary organic aerosols and OPAHs (quinones) were shown to induce ROS formation (Charrier et al., 2014; Bates et al., 2019). Polycyclic

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aromatic compounds (PAHs, OPAHs, AZAs) can cause oxidative DNA damage and DNA adduct formation (Clerg´e et al., 2019; Xue and Warshawsky, 2005; Yamada et al., 2004; Bolton et al., 2000) that can result in carcinogenic/mutagenic effects and cancers. Increased levels of ROS has been seen to enhance viral multiplication (Reshi et al., 2014). With the current pandemic, COVID-19, the presence of high-level PM in the environment tends to increase the disease's effects due to increased ROS (Bakadia et al., 2021).

The anthropogenic particulate matter generated in households with poor ventilation tends to pose a serious health threat to many (Cheek., 2021; Lee et al., 2002). Indoor activities such as cooking, use of air conditioners, cleaning, and house fumigation are among the suspects of high concentrations of particulate matter in households(Tsai, 2019). The cooking process is characterised by the emission of PM and volatile organic compounds, which are a result of isomerisation, condensation, hydrolysis, thermal degradation, myriad reactions and recombination between chemical constituents of oils, fats, solid food and water under elevated temperatures of over 250 ° C (Abdullahi et al., 2013; Fardet, 2018; Mahadevan Subramanya & Savage, 2021). The concentration, size and composition of PM emissions during cooking are determined by factors such as cooking methods, types of food being cooked, cooking oils and additives (Bandowe et al., 2021; Chen et al., 2018; Lin et al., 2021; O'Leary et al., 2019; Saito et al., 2014; Takhar, 2021; Torkmahalleh et al., 2012; Torkmahalleh et al., 2017).

Table 1: Particulate Matter Concentrations and their Sources

Author/Year	**Type Of Cooking Style/Food**	**Concentrations of PM**
(Zhang et al., 2010)	- frying chicken, shrimp and vegetables(Chinese) -boiling pasta and subsequently stir-frying it with vegetables(Italian) - Indian cooking involved pan-frying chicken, peppers and vegetables	Av. Ultrafine particulate matter concentrations ranged from 1.34×10^4 to 6.04×10^5 particles/cm^3 -Av. $PM_{2.5}$ mass concentration ranged from 1.34×10^4 to 6.04×10^5 particles/cm^3, 10.0 to 230.9 μg/m^3
(Lee, Li, & Chan, 2001)	Korean berbacue	average levels of PM_{10} and $PM_{2.5}$ were as high as 1442 and 1167 μg/m^3, respectively
(To & Yeung, 2011)	Deep frying of tofu Griddle frying of meat Frying vermicelli with beef Pan-frying of meat Deep frying of chicken wings	4.72 (mgm^{-3}) 2.26(mgm^{-3}) 1.33(mgm^{-3}) 1.02 (mgm^{-3}) 0.89(mgm^{-3})

(He et al., 2004)	Chinese Hunan Cooking and Cantonese Cooking style	Fine particles average concentrations were 1406.3±7293.4 μgm^{-3} and 672.0 ± 7295.8 μgm^{-3} in Hunan cooking and Cantonese cooking, respectively. (PM2.5 size accounted for 20.7 %)
(Glytsos et al., 2010)	Frying an onion slice with olive oil using an electric griddle	1.2× 10^5 particles/cm^3
(Kong et al., 2021)	Korean cuisine; Roasting of Pork belly and mackerel	PM_{10} concentrations were 246.27 and 1227.71 $\mu g/m^3$ $PM_{2.5}$ concentrations were 161.93 and 760.82 $\mu g/m^3$
(He et al., 2004)	smoking, frying and grilling	During smoking, frying and grilling, the PM2.5 concentrations could be 3, 30 and 90 times higher than the background levels, respectively.
(Bordado et al., 2012)	-Typical Portuguese dishes by gas-burning (bacon), boiling(fish) and frying(meat)	Ultrafine PM 42.7 $\mu m^2/cm^3$ (increased to 72.9 $\mu m^2/cm^3$ due to gas-burning) to a maximum of 890.3 $\mu m^2/cm^3$ measured during fish boiling in water, and a maximum of 4500 $\mu m^2/cm^3$ during meat frying.
(Alves et al., 2021)	fried horse mackerel, stuffed chicken, grilled pork and fried pork	PM10- fried horse mackerel (71.1 μgm^{-3}), stuffed chicken(24.3 μgm^{-3}), grilled pork(73.1μgm^{-3}) and fried pork(32.4μgm^{-3})
(Abdullahi et al., 2018)	Chinese -Chicken Kun pao with rice(Stir fry) Western- Chicken, eggs and chips (Deep fry) Indian- Chicken tikka masala with rice (Stew) -African- Chicken in tomato stew with rice and plantain (Deep frying, stew)	-368 ± 83 $\mu g\ m^{-3}$ -470 ± 263 $\mu g\ m^{-3}$ -99 ± 19 $\mu g\ m^{-3}$ - 81 ± 12 (s.d.) $\mu g\ m^{-3}$
(Giwa et al., 2019)	-Frying	-Kerosene-$PM_{2.5}$ = 380 µg/m3 ; LPG-, $PM_{2.5}$ = 361 µg/m3

	-stewing -boiling	-Kerosene $PM_{2.5}$ = 341 µg/m3; LPG,$PM_{2.5}$ = 329 µg/m3 -Kerosene $PM_{2.5}$ = 339 µg/m3; LPG, $PM_{2.5}$ = 310 µg/m3
(Li et al., 2021)	Stir fry (pork and carbage) Deep fry (fish)	-PM $_{2.5}$ 161.15 µg/m^3 -PM $_{2.5}$ 176.50 µg/m3
(Lenssen et al., 2022)	Barbecue cooking (grilling)	-smoke emitted by barbecue measured av. Concentrations of PM2.5 between 553 to 1062 µg/m^3
(Mehdi et al., 2018)	Pan grilling of meat	PM concentration ranged from 1.5 × 10^4 to 3.3 × 10^4 particles/cm^3
(Lu et al., 2019)	Chinese cuisine deep-frying stir-frying stewing quick-frying boiling Steaming	 -PM2.5 ranged from 0.709–2.731 mg/m^3 -(0.700–0.958 mg/m^3) ~0.573 mg/m^3) -(0.140–0.433 mg/m^3) -(0.004–0.247 mg/m^3) -(0.011–0.088 mg/m^3),
(Won et al., 2020)	Korean dishes -Roasting pork -Frying pork -Boiling pork	Mean number concentrations; 2.5 × 10^6 cm^{-3} 2.3 × 10^6 cm^{-3} 9.6 × 10^5 cm^{-3}
(Mostafa et al., 2021)	Cooking (style not specified)	Approx. 1.2 × 10^5 particles/cm3
(Zhao et al., 2019)	Stir-frying Pan-frying Deep-frying	PM rates of emission;180.09–270.59 ng/min 240.51–241.61 ng/min 79.87–117.59 ng/min

	Steaming Boiling	37.86 ng/min 8.83ng/min

Conversations surrounding the effects of fine and ultrafine particulate matter on the human respiratory tract system in recent years has been the talk (Goodsite et al., 2021; Kumar et al., 2021; Sharma et al., 2021; Silvani et al., 2019). Exposure to fine and ultrafine PM has been seen to be the culprits of oxidative stress and inflammation of lungs, and cardiovascular alteration (Aztatzi-Aguilar et al., 2018). Furthermore, the examination has demonstrated that PM10 or PM2.5 can reside in the lungs and can cause gradual sickness from gentle to extreme cases that can be fatal (Chen et al., 2018). Furthermore, a few epidemiological investigations have shown that nonstop presentation to high groupings of PM, particularly ultrafine ones, have a relationship with human respiratory and cardiovascular wellbeing dangers (Burnett et al., 2014; Hosgood et al., 2011; Maji et al., 2018).

3.0 METHODOLOGY

The determination of morphology and particulate matter of meat pyrolysis by products was done using scanning electron microscopy (SEM) as described by Rono et al. (2017). Particulate emission from the pyrolysis of meat at 500 ˚C and 700 ˚C at a residence time of 15 minutes was dissolved in dichloromethane through a porous tube diluter and transferred into amber vials. About 5 mg of the particulate sample was added to 1 mL methanol and gold grids were dipped into the prepared sample. Twisters were used to pick the gold grids from the sample. The grids were allowed to dry in the open before putting them into the analysis chamber of the SEM (JEOL JMS 7100F). The sample was analysed under high vacuum to avoid interference by air molecules during analysis. The SEM machine was then switched on and imaging of the sample conducted. The lens was tuned at various resolutions until a clear focus of the sample was observed. Image J computer program was used to determine the size of the soot particles and a distribution curve of particulate size was then determined using Igor 5.0 computer software. The mean sizes of the soot particles at 500 and 700 ˚C were reported and presented as Gaussian distributions, where the peak of the curve showed the average of the particle size.

4.0 RESULTS AND DISCUSSION

Cooking Methods and Associated Particulate Matter

Cooking styles and methods vary from region to region or continent to continent. This has necessitated the classification adapted as indicated in table 1. A thorough literature search has been done to evaluate the influence of cooking style on PM concentration in the indoor environment. In general, these studies have demonstrated that indoor PM concentrations are largely affected by cooking styles, oils used, and the nature of the culinary being prepared (Alves et al., 2021).

An experimental study done by Li et al. (2021) noted that deep-frying as one of the methods leads to emission of high concentrations of $PM_{2.5}$ as opposed to stirring fry method in fresh air system than in window ventilated system. Additionally, reports from Mostafa et al. (2021) indicated that PM concentrations in the indoor air were at their maxima five minutes after the cooking process had elapsed, and the clearing process of PM took roughly 30 minutes, suggesting low removal of these particles in the air. These results show how human beings can be continually be exposed to dangerous PM through cooking long after their cooking has ended.

Chemical components embedded in PM emitted from cooking styles has been found to be carcinogenic and mutagenic, though this review does not consider literature for chemical components of particulate matter generated from cooking. However, the cooking technique reported literature had shown clearly that it has a great consequence on the emission profiles of particulate matter, PM2.5, in the indoor air quality (Chen et al., 2018).

A research study carried out by Rono et al., 2017 showed that the mean particle size of particulates obtained by roasting meat at 500 °C 7.72 ± 0.61 μm while at 700 ˚C, the particulate size of emissions was found to be 3.52 ± 0.31 μm Fig. 1. A report to determine the ventilation conditions required for suitable indoor air quality during cooking in a typical South Korean residential home indicated that Roasting of Pork belly and mackerel PM10 concentrations were very high (246.27 and 1227.71 µg/m3) in the absence of ventilation while PM2.5 concentrations (161.93 and 760.82 µg/m3) upon the use of air cleaners and different hoods never showed any decline (Kong et al., 2021). Frying as a common method of cooking embraced in most households worldwide has not been better either due to high PM emissions.

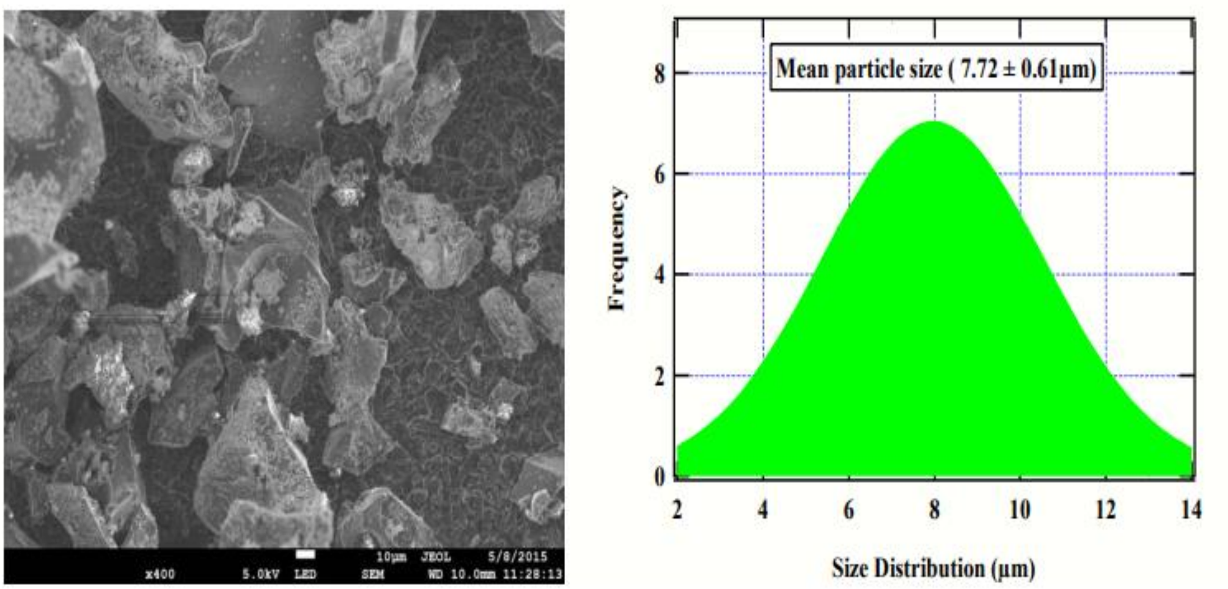

Figure 1: **Scanning Electron Microscopy Image and Particle Size Distribution of Soot Particles of Roasting Meat at 500 ˚C (Rono et al., 2017).**

Findings from experimental research to determine the aerosols resulting from common domestic cooking activities (boiling fish, vegetables, or pasta, and frying hamburgers and eggs) indicated high scores of particulate matter in meat frying (maximum of 4500 $\mu m^2/cm^3$) as opposed to gas-burning (72.9 $\mu m^2/cm^3$) and boiling (890.3 $\mu m^2/cm^3$) methods (Bordado et al., 2012).

Multipath Particle Deposition (MPPD) Computational Software.

Applied Research Associates, Inc. developed the multiple Path Particle Deposition (MPPD) model to mimic the inspiration and respiration of particulate matter in human lungs. The MPPD model is a computational semi-empirical dosimetry model based on the physical and physiological parameters that govern the particulate matter transport within the respiratory tract (Zwozdziak et al., 2017). The use of computational models makes research faster and cheaper due to the cost of the model as well as the high accuracy of the accurate results. In addition, this model makes it possible for otherwise laboratory experiments that are tedious to be carried out. The main objective of this review is to establish the dangers posed by inhaling respirable PM associated with cooking styles. A study (Oh et al., 2021) to establish the daily particle deposition mass for two age groups showed that 8.64 $\times 10^{-5}$ µg (age 8) to 8.64 $\times 10^{-4}$ µg (age 21) were distributed in the lung system. MPPD models allow us to understand the regional deposition of particulate matter from research done by the fine particles, deposited 50 per cent in the head, 17 per cent in the trachea and bronchial and 33 per cent in the pulmonary region. In comparison, coarse particles deposited 84 per cent in the head, 5 per cent in the trachea and bronchial and 11 per cent in the pulmonary region (Rajput et al., 2019). This result clearly shows that the smaller the particulate size, the more it travels deep in the respiratory tract; for instance, deposition of $PM_{2.5}$ in the alveolar region was established to be higher than PM_{10} (Manojkumar & Srimuruganandam, 2022; Manojkumar et al., 2019).

5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions: In this review, cooking is the most prominent source of particulate matter in indoor air. Particulate matter emissions are in the range of coarse to ultrafine sizes. Knowing the effects of these particles in the respiratory system through computational models, such as MPPD, makes one be cautious in the cooking methods employed. These particles of this nature are of high surface area, and when inhaled, they can stay in the lungs for long without clearing. Others carry with them persistent free radicals that add more injury to the lungs.

Recommendations: This review, therefore, recommends methods such as boiling and steaming for cooking as opposed to deep-frying, stir-frying, grilling and roasting, which are commonly adopted by fast food hotels/ restaurants worldwide. Further, the use of a well-ventilated kitchen and fast particulate clearing hoods is much encouraged to avoid overexposure to this PM.

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