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ANTICIPATING ADVERSE HEALTH EFFECTS ON COOKS FROM EXPOSURE TO RESPIRABLE PARTICULATE MATTER ($PM_{2.5}$) AND CARBON MONOXIDE(CO) FROM BURNING OF COOKING FUELS

Vaishali Bhole Jaiswal[1] Pravin U. Meshram[2]

1:- Research Scholar , Department of Environmental Science ,SMM, Rashtrasant Tukdoji Maharaj Nagpur University and ARO ,Dept of Epidemiology ,NIHFW ,New Delhi -110067
2: Corresponding Author === Dr P. U. Meshram, Associate Professor and Head, Department of Environmental Science,
Sevadal Mahila Mahavidyalaya and Research Academy
Sakkardara Square, Nagpur-440 009

Abstract

The use of biomass fuels for cooking is the source of household air pollution in India, particularly in rural areas. The emissions of particulate matter, especially less than 2.5 microns ($PM_{2.5}$) and carbon monoxide(CO), were observed during cooking and non-cooking periods in rural households of Nagpur district in Maharashtra. Various stove types (Chulah and LPG) and fuel types (dung cake, crop residues, wood (biomass fuel) and LPG), monitored for emissions, thus representing a significant fraction of the total fuel/stove combinations used in the study area. During cooking, the CO concentrations ranged from 0.18 ppm to 66 ppm when cooking was done indoors in gas and biomass fuel-using households, respectively. Similarly, the $PM_{2.5}$ concentrations during cooking ranged from 4.8 ug/m^3 to 11500 ug/m^3 and 10 to 4200 when cooking was done indoors in wood and gas using households respectively .Combining the results of the time-activity pattern of cook , $PM_{2.5}$ and CO concentrations during cooking and non-cooking periods, exposure estimates for cook calculated. In rural households ventilation is limited. Exposures experienced by household members, particularly women who spend a large proportion of their time in the kitchen, have been measured to be many times higher than WHO guidelines and national standards.

Keywords: Adverse health, PM 2.5,Exhaled breath carbon monoxide; COHb%; household air pollution; Cooking fuels; Rural woman; Exposure;

Introduction

Total Suspended Particulate matter (TSP) includes all suspended particulates, both from natural sources, suspended dust, products of incomplete combustion (organic carbon (OC), Black carbon (BC) and elemental carbon (EC). These are primary constituents of atmospheric aerosols produced from incomplete combustion of biomass burning emission (1) and secondary pollutants like e.g., sulfates formed from SO_2. Particulates may damage crops and human health, and there is a growing awareness of the particulates' global warming potential. Harmfulness of the particulates to human health depends on size and composition of the particles, thus the origin of the particles is important. In epidemiology, the particulates normally classified by size. Particulates with an aerodynamic diameter bigger than 10µm are normally removed by the upper airway and have minor respiratory health effects. Particulates smaller than 10µm are called inhalable particles or PM_{10} and may penetrate beyond the trachea and the large bronchi causing health damage. Fine respirable particles with an aerodynamic diameter smaller than 2.5µm, $PM_{2.5}$, may penetrate the lungs' smaller airways. These represent the largest health hazard. The World Health Organization has recently published updated air quality guidelines (2). The new guideline for PM_{10} set at 20µg/m^3 annual mean and 50µg/m^3 24-hour mean and half for $PM_{2.5}$. WHO recommends using the $PM_{2.5}$ guidelines, suggesting a $PM_{2.5}/PM_{10}$ fraction of 0.5. Although health effects cannot be ruled out at the guideline level, the levels represent annual averages that are achievable in large urban areas in highly developed countries. Wood and other solid fuel smoke particles are generally smaller than 1 µm, with a peak in the size distribution between 0.15 and 0.4 µm (3,4), with a significant number in the ultrafine range (less than 100nm in diameter) that condense rapidly as they cool and age. In addition, the smoke also contains ash and solid fuel debris. The aerodynamic diameter of the particle is a major determinant where the deposition may occur in the respiratory tract and, consequently, is also important for the nature and extent of health effects.

Women, who use solid fuels for heating and cooking, experience highest cumulative lifetime CO exposure (5) .Once breath-in, CO binds to hemoglobin with an affinity 250–300 times than that of oxygen (6). It forms carboxyhemoglobin (COHb), results in a decrease in the amount of oxygen in blood causing tissue hypoxia (7). Acute exposure to CO causes health effects, including headaches, dizziness, muscular cramping, vomiting, unconsciousness, and death (8, 9). Exposure to levels as low as 2.5% of COHb is related to an enhanced risk of ischemic heart disease (10). CO body burden can be measured by COHb concentration from venous or arterial blood, which is considered the standard method. (11, 9).

COHb is a biological indicator of the concentration of CO in the body. Measuring COHb levels is not feasible due to the invasive nature of collecting blood samples. Shortage of trained professionals for collecting blood samples and adequate storage facilities in rural areas makes it more difficult. An alternative technique is a measurement of exhaled breath CO, which provides an assessment of COHb percentage levels in a non-invasive manner (12, 13, and 14). India, where the large population lives in rural areas and a majority of this population (~80%) is dependent on biomass fuels for cooking, emission of CO due to incomplete combustion during cooking is a widespread problem (15,16). Earlier studies focused only on CO's measurement in the indoor/outdoor atmosphere without investigating the biological response of CO inhaled during the exposure. The present study investigates the exhaled breath CO in different groups of women who cook with different fuels such as biomass fuel (dung cakes, crop residues, firewood), and liquid petroleum gas (LPG) in a typical rural setting in the Nagpur district of Maharashtra, India. The study identifies the cause and effect relationship between CO concentrations during the cooking cycle of different fuel type's location (outdoor/indoor) and assesses the incidence of CO poisoning symptoms. It can be a better indicator than PM_{10} for anthropogenic suspended particles in many areas. Measurement of size fractioning of a particle is generally done in health impact studies as the particle deposition or penetration in the human body depends on the particle size cut off. Therefore, $PM_{2.5}$ fractions, along with CO, were monitored in study households.

METHODOLOGY

The study carried out in the rural area of Nagpur district in the state of Maharashtra during the year 2017-18. The study was crossectional and used the stratified random sampling technique. The stratification done at three levels: district, tehsil (block), and village to identify the study area. District Nagpur has fourteen blocks, out of which Katol was selected randomly for the study, 82.38% biomass fuel use according to Census 2011(17). Twenty villages selected from the block based on their distance from the block headquarter. All procedures followed the ethical standards of the Institutional Review Board and the Helsinki declaration of 1975 that revised in 2000. Ethical clearance taken from the Institutional Ethics Committee of Rashtrasant Tukdoji Maharaj Nagpur University. Informed consent obtained from all subjects of the study. The survey was conducted at two levels, viz., individual, and household. The study population was rural women cooks using different types of fuels for cooking and the community. Women aged 15 years and above involved in cooking and non-smokers, non-pregnant women included in the study. 450 households selected for collecting primary data on several household parameters like socio-economic, demographic, and housing characteristics. The respondents' age ranged from 22–55 years, with the mean age being 36.5 years.

A pre-tested questionnaire used to collect information regarding the type of fuel and stove used, the amount of time spent in cooking, and other sources of CO exposure like tobacco smoke. It also contained questions on the respiratory symptoms such as cough, phlegm,nasal obstruction,sneezing, chestpain, headache, nausea, dizziness, and shortness of breath due to CO poisoning. Further, CO concentration in the breathing zone atmosphere of the cooking area (indoor/outdoor) measured at each site covering the entire cooking-cycle.

In the case of biomass fuels, cooking is indoors and outdoors (in the courtyard), whereas LPG is strictly indoors. Breath CO was measured using a portable breath CO analyzer (Smokerlyzer by Bedfont- Scientific, Ltd., Kent, UK) using a standard procedure. The Smokerlyzer can detect CO in the range 0– 100 ppm. The instrument's operating temperature and humidity range is 0–40°C and 10–90%, respectively. The exhaled breath measurements done in the morning (5.30–6.30 am) during winter months when the ambient temperatures generally remain between 20–25°C. The instrument has an organic filter that prevents inaccuracies caused by other breath components such as alcohol or ketones. It contains an electrochemical CO sensor and reference electrodes separated by a thin layer of electrolyte. The CO present in the air diffuses the sensing electrode reacts at the surface by oxidation, to create an electrical charge that is then measured and converted into a ppm reading. The reaction involved given below.

$$CO + H2O \rightarrow CO2 + 2H+ + 2e-$$

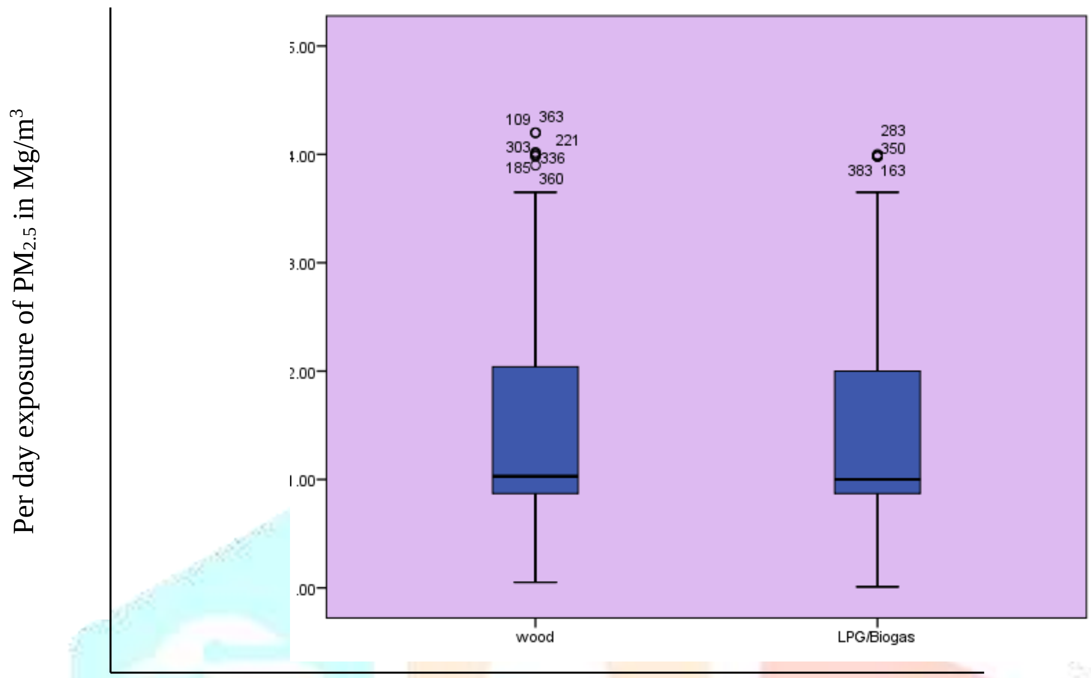
The Smokerlyzer shows the levels of CO in the blood, depicted as %COHb, the actual medium monitored is CO on the breath in parts per million (ppm). Proper technique for exhaled breath measurement demonstrated to each subject before data collection. Exhaled CO levels were measured by asking the subjects to inhale deeply, hold the breath for 15 seconds, and then exhale slowly into the instrument's mouthpiece after the ready light indicated that sampling could begin. Repeat measurements done only when the subject failed to do it properly. Exhaled breath CO of each cook measured twice a day; first in the early morning, just before the fire was lit and then immediately after the end of the cooking cycle. The 'cooking cycle' begins with the time instant when CO starts rising due to combustion activity during cooking and ends when the CO levels reach the background levels. The CO levels were measured in the cooking area during cooking in all the study households by using the instrument Testo 350 XL (Testo Ltd, Germany). CO measurements conducted within the breathing zone of the cook according to standard protocols. Since in biomass-using households, women usually performed cooking in sitting position on the floor, therefore the monitors were placed at 2.5 feet above the floor level on a stool and 3 feet away from the stove. LPG users, on the other hand, generally cooked in a standing position, and therefore, the monitors were placed accordingly at the height of 4 feet and 3 feet away from the stove. The instrument has electrochemical sensors for the instantaneous measurement of CO, measured continuously at an interval of one minute for the entire cooking cycle. The instrument had data loggers, which stored minute-by-minute data in their memories over the entire measurement period. These data downloaded into a personal computer after monitoring

Statistical Analysis Statistical analysis of the data collected on CO and $PM_{2.5}$ in the breathing zone atmosphere and exhaled breath CO done in microsoft excel and SPSS software. Data handling and preliminary computations were done in microsoft excel. Analysis of variance (one-way) was done in SPSS to investigate the significance of the difference between the average CO concentration during the cooking cycle of each fuel type and the exhaled breath CO among the subjects using different fuel types.

Results

A total of 450 households monitored. Fig 1 presents the trends of respirable particulate matter ($PM_{2.5}$) concentrations in the kitchen/cooking area during cooking with various kinds of fuel. The trends of concentrations of $PM_{2.5}$ during non-cooking and outdoor areas also shown. The analysis indicate that the use of wood resulted in the highest concentrations, followed by gas. The cooking area affected the concentration of $PM_{2.5}$ immensely as the concentrations were quite high when cooking was done indoors compared to when it done outdoors using the same fuel/stove combinations. The $PM_{2.5}$ concentrations during cooking ranged from 4.8 ug/m^3 to 11500 ug/m^3 and 10 to 4200 when cooking was done indoors in wood and gas using households respectively. The concentrations reduced when cooking done outdoors. One-way ANOVA analysis of concentrations across fuel categories shows that the levels at both locations are significantly different across fuel types ($p<0.01$).

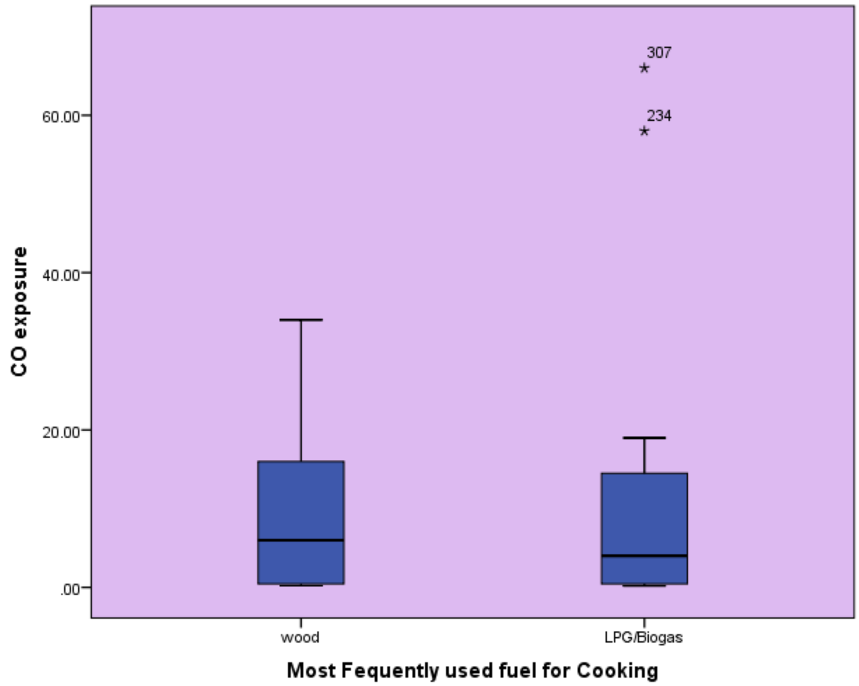
Figure No. 1: Average respirable particulate matter ($PM_{2.5}$) concentrations during cooking with various kinds of fuel



Most frequently used fuel.

Fig 1 presents the trends of CO in the kitchen/cooking area during cooking with various kinds of fuel and stoves. The results indicate that the use of wood resulted in the highest concentrations, followed by gas. During cooking, the CO concentrations ranged from 0.18 ppm to 66 ppm (Fig 1.2) when cooking was done indoors in gas and solid fuel-using households, respectively. The concentrations were reduced to almost half when cooking done in outdoors. One-way ANOVA analysis of concentrations across fuel categories shows that the levels at both locations are significantly different across fuel types ($p<0.01$) (Table 1). The average CO concentrations during non-cooking periods and outdoor air were .01 ppm and 1.0 ppm, respectively.

Figure No. 2.: Average CO concentrations during cooking with various kinds of fuel



Cooking activity among subjects exposed to CO emitted by different fuel types. It is seen that before cooking exhaled breath, CO levels are approximately the same (~1 ppm) among subjects of all categories of fuel types. After cooking exhaled breath CO levels reflect the high levels of CO emitted by different biomass fuels. No difference is observed between the before and after cooking exhaled breath CO levels in case of LPG users. After cooking exhaled breath CO levels are found to be significantly higher among the users of different biomass fuels. It is seen that the mean exhaled breath CO levels after cooking are the highest in the case of biomass users, and LPG users, respectively.

Table No. 1: ANNOVA for COHb levels before and after cooking

		Sum of Square	Df	Mean Square	Std. Deviation	Sig
COHb Before	Between Groups	.461	3	.154	3.591	0.023
	Within Groups	1.496	35	.043		
	Total	**1.957**	**38**			
COHb After	Between Groups	3.127	3	1.042	5.851	0.002
	Within Groups	6.236	35	.178		
	Total	**9.364**	**38**			

Table No. 2: ANNOVA of exposure levels of CO & $PM_{2.5}$ with most frequently used fuel

Type of Fuel	Statistics	Exposure Co (PPM)	Exposure $PM_{2.5}$ (mg/m^3)
Wood	N	214	214
	Mean	1.9953	2.0000
	Std. Deviation	0.98580	1.01630
LPG/Biogas	N	236	236
	Mean	1.8517	1.8305
	Std. Deviation	.89872	.92534
	P-value	.010	.055

The results of ANOVA (Table 2) further confirm that the mean exhaled breath CO levels among different fuel type users are significantly different. The higher exhaled breath CO levels among biomass fuel users in the present study indicate that the smoke from the burning of biomass fuels caused a significant body burden of CO i.e., 5–9 ppm of exhaled CO for different biomass fuels. In a similar study on rural women of Guatemala, Díaz et al. (2007) report exhaled breath CO levels of 9 ppm among the cooks using biomass fuel in traditional cookstoves (18). The breath CO levels of LPG users in the present study are comparable to the levels reported by earlier studies on healthy subjects (19, 20).

One-way ANOVA analysis of cooking area concentrations across fuel categories shows that the levels were significantly different across fuel types. Time spent by cook near fire varies from house to house, and it ranged from 1-6 hour/day depending on the number of family members for whom food is cooked. The analysis of exposures levels for cooks across households using various fuels shows that exposures were significantly different across fuel categories (fig.2). This parallels the trends in both $PM_{2.5}$ as well as CO concentrations that were also significantly different across fuel types. Wood produced the highest concentrations and exposures followed by gas. This suggests that average household exposures are reflected well by the average concentration.

Table No. 3: Symptoms over last twelve months across fuel types (As reported by women cook)

Respiratory Index	Wood	LPG	Total	P value
Cough	151(70.6)	162(68.6)	313(69.6)	>0.05
Phelgm	135(65.2)	144(61.5)	279(63.3)	>0.05
Nasal discharge	31(14.5)	25()10.6)	56(12.4)	>0.05
Nasal Obstruction				
Sneezing	49(22.9)	49(20.8)	98(21.8)	>0.05
Chest pain	143(66.8)	132(55.9)	275(61.1)	**<0.05**
Shortness of breath	138(64.5)	132(53.8)	270(60.0)	**<0.05**
Non Respiratory Index				
Eye irritation	136(65.4)	133(56.6)	269(60.7)	**<0.05**
Wheezy chest	105(49.1)	109(46.2)	214(47.6)	>0.05
CO symptoms				
Dizziness	103(48.1)	106(44.6)	209(46.4)	>0.05
Headache	205(95.8)	219(92.8)	424(94.2)	>0.05
Nausea	25(11.7)	29(12.3)	54(12.0)	>0.05
Other	11.7%	12.3%	12.0%	
Joint pain	36(16.8)	54(22.9)	90(20)	>0.05
Blackout	133(62.1)	127(53.8)	260(57.8)	**<0.001**

Table no. 3 describes the comparison of symptoms/morbidities in different fuel users. Participants experienced various symptoms like eye irritation, headache, giddiness, dry cough, and nasal irritation during cooking. The prevalence of symptoms like eye irritation, headache, and dry cough was higher among biomass users as compared with, LPG. Chi-square test across all cooking fuel categories revealed statistically significant difference for eye irritation, chest pain, blackout (P<0.01) and breathlessness (*P* < 0.05). Furthermore, the prevalence of morbid conditions was found to be significantly higher among biomass users for Dysnosea (64.5%), chestpain (66.8%), eye irritation (65.4%) and blackout (62.1%) compared with other fuels.

Discussion

As the combustion of solid biomass fuels in traditional cookstoves emits directly into human occupancy, exposures to certain air pollutants derived from these sources are often greater than those derived from outdoor sources. Initial studies on HAP measured concentrations of total suspended particulates and gases, including CO, only during cooking windows. Determination of 24-hour averages for inhalable fractions of particulate matter (which is a better metric for exposure and health risks, and for which health-based standards exist in outdoor settings) have attempted in very few studies. The latest National Ambient Air Quality Standards of the U.S. Environmental Protection Agency requires the daily average concentration of PM10 (particulate matter less than 10µm in diameter) to be less than 150µg/m3 and annual average to be less than 50µg/m3 (21). In contrast, concentration PM10 ranged from 500-2000 microgram/m3 during cooking in typical Indian households (22). In addition to particulate matter, the burning of biomass emits smoke that contains high levels of pollutants like carbon monoxide, oxides of nitrogen and Sulphur, formaldehyde, benzo(a)pyrene and benzene which are hazardous for human health (23). Besides morbidity, HAP from biomass burning in developing countries is believed to be responsible for an estimated 3.8 million premature deaths every year (WHO, 2016). India alone registers over 4,82,000 premature deaths per year that can be attributed to HAP (2).

Kandpal et al. (24) tested four types of biomass fuels: animal dung cake, crop residue (mustard stalk), fuelwood (Acacia), and a mixture of fuelwood and dung cake in traditional U-shaped cookstoves and improved mud cookstoves. Regardless of which stove was used, the CO concentrations measured in the kitchen air were the highest during the burning of dung cake, followed by the dung-wood mixture, crop residue, and fuelwood. So we can say that the trends found in our study across the tested biomass fuels are consistent with those shown in earlier studies Smith et al. found the measured levels of health-damaging pollutants from biomass stoves more than ten times higher than those specified in the relevant standards. The CO standards for the residential area are 2 mg/m3 of 8-h average (16 hmg/m3 exposure equivalent) in India. These national standards could easily exceeded by CO exposures caused by traditional biomass stoves. In households with limited ventilation, exposures experienced by household members, particularly women and young children have been measured to be many times higher than World Health Organization (WHO) guidelines and national standards set by CPCB [25]. Emissions contain many other toxic and potentially toxic compounds. These are carcinogenic VOCs (e.g., benzene, 1,3-butadiene), sulfur dioxide, and nitrogen dioxide aldehydes, polycyclic aromatic hydrocarbons, and particulate matter [26]. These pollutants sum up together to produce health risks for people who repeatedly exposed to the emissions. The WHO estimates that 22% of all COPD is caused by exposure to indoor smoke from biomass fire. Incidence of cough, phlegm breathlessness, wheezing and eye irritation are also significantly higher in households using biomass fuels compared to those using gas for cooking [27]

Conclusion

The present study reveals that use of biomass fuels leads to very high levels of CO in the breathing zone atmosphere of the cooks among rural women in the Nagpur rural region. These levels far exceed the indoor standards prescribed by WHO. Measurements of exhaled breath CO after the cooking cycle reveals the prevalence of high exhaled breath CO levels among the biomass fuel users. A very high positive correlation is obtained between average CO levels during the cooking cycle and exhaled breath CO after the cooking cycle. The results of the questionnaire survey show that CO poisoning symptoms such as headache, nausea, dizziness and shortness of breath have significantly higher incidence among the biomass fuel using cooks. Given the extensive use of biomass fuels in developing countries like India, especially by the poor rural populations, for whom data on exposure to pollutants are limited, testing of exhaled breath CO has the potential to be used as a cost-effective, noninvasive, and immediate method of estimating CO body burden.

The findings of this study strengthen the evidence that the use of biomass fuels/traditional stoves for household energy exposes the cook to levels of household air pollution that exceeded health guidelines available for outdoor air quality; this holds true even when cooking is done outside the house in the open air or a separate kitchen. Women, in their traditional capacity as cooks, had much greater exposures than other family members emphasizing an important gender dimension of the IAP problem.

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