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Non-Invasive Measurement of Carbon Monoxide in Rural Indian Woman Exposed to Different Cooking Fuel Smoke

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ABSTRACT

In India more than 70% of the population use biomass fuels for cooking. Women, who traditionally carry out the cooking in this culture, experience the highest lifetime Carbon Monoxide (CO) exposure due to the burning of such fuels in traditional stoves. CO levels were measured in this study in the breathing zone atmosphere of cooks during the cooking cycle, using different fuels such as LPG, wood, crop residues and dung cakes, in a rural area of the National Capital Region (NCR) of India. The exhaled breath CO levels of the non-smoking female cooks were also measured before and after cooking. A high degree of correlation was obtained between CO levels during the cooking cycle and exhaled breath CO levels. The study suggests that the enhanced exhaled breath CO levels of the cooks were largely due to the burning of biomass fuels. A high value of R^2 (0.79) was obtained during the model fitting exercise, which suggests the usefulness of fuel-type and cooking location (i.e., indoor/outdoor) as explanatory variables for predicting exhaled breath CO levels among cooks. The prevalence of CO poisoning symptoms was found to be significantly higher among the biomass fuel users. The study demonstrates the potential of the exhaled breath CO technique as a non-invasive, easy and economical alternative for predicting CO exposure due to the burning of biomass fuel in rural settings, where it may not always be possible to collect CO exposure data using the conventional invasive techniques.

Keywords: Exhaled breath carbon monoxide; COHb%; Indoor air pollution; Cooking fuels; Rural woman; Exposure; Health.

INTRODUCTION

In India more than 70% people use biomass fuels for cooking (NFHS-III, 2006). These fuels when burnt in traditional stoves produce pollutants such as particulate matter and carbon monoxide in concentrations, which far exceed the World Health Organization standards for ambient air quality (WHO, 2010). It has been estimated that indoor air pollution from cooking with biomass fuels is responsible for 1.6 million deaths each year, mainly due to respiratory infections in children and chronic obstructive pulmonary diseases (COPD) in adults (WHO, 2002; Smith, 2004; Bruce, 2006; Dherani, 2008). Exposure to pollutants is particularly high for women and children as they spend more time indoors (Balakrishnan, 2002; Ezzati, 2002; Mestl, 2007; Jiang, 2008). Women, who rely on solid fuels for heating and cooking, experience highest cumulative lifetime CO exposure (Smith, 2004). Once inhaled, CO binds to hemoglobin with an affinity 250–300 times than that of oxygen (Raub, 2000), thereby forming carboxyhemoglobin (COHb). This results in a decrease in the amount of oxygen in blood, thus causing tissue hypoxia (Roughton, 1944; Piantadosi, 1996). Health effects from acute exposures to CO include headache, dizziness, muscular cramping, vomiting, unconsciousness and death (Penney, 1996; Kao and Nanagas, 2005). Chronic exposure to levels as low as 2.5% of COHb are associated with an increased risk of ischemic heart disease (WHO, 2010). Measuring COHb concentration from venous or arterial blood is considered the standard and most direct method for measuring CO body burden (Widdop, 2002; Kao and Nanagas, 2005). Even though COHb is a biological indicator of the concentration of CO in the body, measuring COHb levels is not always possible due to the invasive nature of collecting blood samples. In addition, collection and storage of blood sample requires trained professionals and adequate storage facilities, which are not feasible in rural settings. Measurement of exhaled breath CO is an alternative technique that can provide an estimation of COHb percentage levels in a non-invasive manner (Cohen *et al.*, 1971; Stewart *et al.*, 1976; Jabara *et al.*, 1980). In a

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developing country like India, where large population lives in rural areas and a majority of this population (~70%) is dependent on biomass fuels for cooking, emission of CO due to incomplete combustion during cooking is a widespread problem (P Smith, 1991; atel and Riyani, 1995). However, despite the potential usefulness of exhaled breath CO as an indicator of COHb levels, most of these studies have focused only on the measurement of CO in 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 dung cakes, crop residues, firewood and liquid petroleum gas (LPG) in a typical rural setting in the National Capital Region (NCR) of India. This is the first study in the Indian context which clearly identifies the cause and effect relationship between CO concentrations during the cooking cycle of different fuel types and exhaled breath CO, models exhaled breath CO on the basis of fuel type and cooking location (outdoor/indoor), and assesses the incidence of CO poisoning symptoms among the exposed population. The study clearly establishes the reliability of exhaled breath CO as a useful non-invasive biomarker of CO exposure from cooking.

METHODOLOGY

A total of 80 women cooks were monitored for their exhaled breath CO, covering households of commonly used fuel types in the study area. The study protocols received approval from the Indian Institute of Technology's Student Research committee. Informed consent was obtained from each subject before participation in the study. Breath samples were obtained in accordance with the Helsinki Declaration of 1975, as revisited in 1983. Healthy non-smoking female cooks (n = 80) were randomly recruited from two villages, Nuna Majra and Lowa Khurd of district Jhajjar of Haryana state which, is part of NCR of India. The subjects were recruited after classification on the basis of fuel use. The age of study subjects ranged from 22–55 years with mean age being 36.5 years. A pre-tested interview schedule was used to collect information from the main cook of households regarding the type of fuel and stove used, amount of time spent in cooking and other sources of CO exposure like tobacco smoke etc. The interview schedule also contained questions on the symptoms such as headache, nausea, dizziness and shortness of breath due to CO poisoning. Further, CO concentration in the breathing zone atmosphere of cooking area (indoor/outdoor) was measured at each site covering the entire cooking-cycle.

Study Area and Demographic Characteristics

The study was conducted during the month of November, 2010 in Jhajjar district of Haryana, a state in northern part of India located about 50 Kilometers away from the capital city of New Delhi. The district is located between 76°55′25″ East longitude and 28°43′50″ North latitude at an average elevation of 220 meters (721 feet). The climate of the Jhajjar district can be classified as tropical, semi-arid and hot which is mainly characterized by hot summers (May–June) and cold winters (December–January). The air in the region generally remains dry except during the rainy season which extends from July to mid-September and contributes about 85% of the annual rainfall. As per 2011 census, Jhajjar has a population of 958,405 of which male and female are 514,667 and 443,738 respectively (Census of India, 2011). Further, nearly 74 percent of Jhajjar's population lives in rural areas. The majority of the households surveyed in the study area were of low to medium incomes, with main occupations either being employment in government or agricultural self-employment. In the study villages, women spend most of their time indoors attending to daily domestic chores such as cooking, housekeeping, child rearing, cattle rearing, making dung cakes, helping in agriculture activities and attending to other household activities. Their staple diet is roti (wheat bread) with locally available vegetables. Rural families traditionally use biomass such as wood, dung, and agricultural residues as cooking fuel in traditional U-shaped earthen stoves called 'Chulah'. In case of biomass fuels cooking takes place both indoors and outdoors (in the courtyard) whereas in LPG it is strictly indoors.

Measuring Exhaled Breath CO

Breath CO was measured using portable breath CO analyzer (Smokerlyzer by Bedfont- Scientific, Ltd., Kent, UK) using a standard procedure that was followed throughout the study. The Smokerlyzer can detect CO in the range 0–100 ppm. The operating temperature and humidity range of the instrument are 0–40°C and 10–90% respectively. In our study the exhaled breath measurements were done in the morning time (5.30–6.30 am) during the month of November when the ambient temperatures generally remain between 20–25°C. The Bedfont instrument has an organic filter that prevents inaccuracies caused by other breath components such as alcohol or ketones. This hand-held breath CO monitor contains an electrochemical CO sensor and reference electrodes separated by a thin layer of electrolyte. The CO present in the air diffusing to 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 is given below.

$$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^- \quad (1)$$

The Smokerlyzer also shows the levels of CO in the blood, represented as %COHb, the actual medium being monitored is CO on the breath in parts per million (ppm). Then the CO monitor show an approximation of CO in the blood as %COHb based on a simple algorithm derived from data from clinical studies showing a relationship between the level of CO in ppm on the breath and the level of CO in the blood (Gomez *et al.*, 2005). The instrument was newly procured for the study and therefore it was pre-calibrated by the manufacturer. As per the manufacturer guidelines the instrument has to be calibrated biannually with 50 ppm CO span gas.

Proper technique for exhaled breath measurement was demonstrated to each subject before data collection. In accordance with the manufacturer's instructions, the exhaled

CO levels were measured by asking the subjects to inhale deeply, hold the breath for 15 seconds and then exhale slowly into the mouthpiece of the instrument, after the ready light indicated that sampling could begin. If the subjects were unable to hold breath for that long, they were asked to hold breath for as long as possible. Single measurement was taken in each case. Repeat measurements were done only when the subject failed to do it properly. Exhaled breath CO of each cook was measured twice a day; first in early morning, just before the fire was lit and then immediately after the end of 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.

Measuring CO during Cooking

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 were 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 a height of 4 feet and 3 feet away from the stove. The instrument has electrochemical sensors for instantaneous measurement of CO which was 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 were then downloaded into a personal computer after monitoring.

Statistical Analysis

Statistical analysis of the data collected on CO in the breathing zone atmosphere and exhaled breath CO was done in Microsoft Excel and SPSS software. Data handling and preliminary computations were done in Microsoft Excel which was also used to obtain the scatter plot between average CO concentration during the cooking cycle and exhaled breath CO. A bivariate linear regression model was also fitted in SPSS to the data on average CO concentration during the cooking cycle and exhaled breath CO. Further, analysis of variance (one-way) was done in SPSS to investigate the significance of difference between the average CO concentration during the cooking cycle of each fuel type and also in the exhaled breath CO among the subjects using different fuel types. Finally, since the data collected in the present study showed strong dependence of exhaled breath CO on the exposure from CO emitted from different fuel types and whether the cooking was done indoor or outdoor, a multiple regression model was developed using the technique of dummy variables (Gujrati, 1995). Dummy variables are binary independent variables employed often in econometrics and behavioural sciences but have potential applications in studies on rural areas where field monitoring of air pollutants may not always be possible. Therefore, the technique of dummy variables was employed to investigate if the exhaled breath CO could be predicted reliably without measuring CO in the breathing zone atmosphere. For this purpose, three dummy variables X_1, X_2 and X_3 were created to represent fuel type (Table 1). Another dummy variable X_4 was created to represent the cooking location i.e., whether indoor or outdoor. This variable took the value 1 when cooking was done indoor and 0 when it was done outdoor.

RESULTS AND DISCUSSION

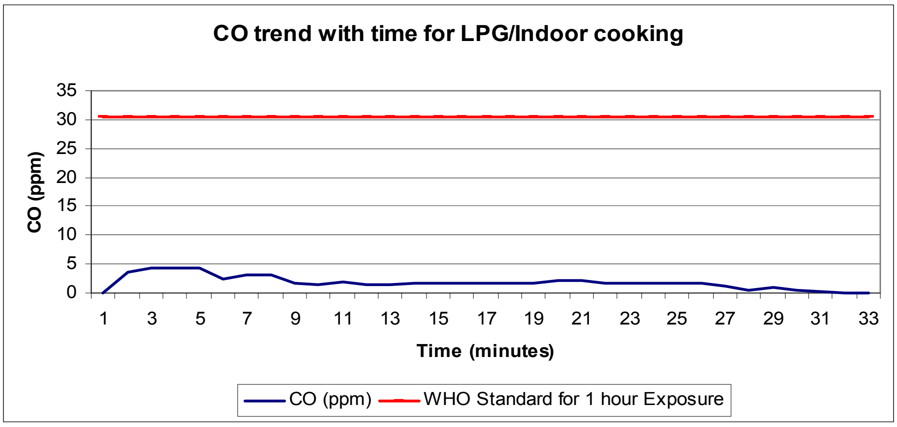
Variations of CO Concentration during the Cooking Cycle

Figs. 1(a)–1(d) represent the time sequence plots of CO concentration in the breathing zone atmosphere of the subjects in the present study. A comparative examination of the plot reveals that CO emission is the least in case of LPG stove which is due to the almost complete combustion that takes place in LPG. Among the other fuel types, it is seen that the concentrations are significantly higher in indoor cooking as compared to outdoor. This is due to the fast dispersion and dilution of emitted CO in the outdoor atmosphere. Further, it is seen that dung-cakes emit the highest CO among the different biomass fuels both in the indoor and the outdoor environment. CO concentrations in case of crop residues are found to be lower than that in case of dung-cakes, while it is found to be the least in wood burning among the three types of biomass fuels. These inferences are further confirmed from Table 2 which represents the descriptive statistical parameters of average CO concentration in the breathing zone atmosphere during the cooking cycle. The results of analysis of variance (Table 3) clearly suggest that average CO during the cooking cycle is significantly influenced by the type of fuel. In this study, the average CO levels in the breathing zone atmosphere of the cook were found to be 277/195, 195/143, 108 and 5 ppm respectively during the cooking cycle with dung cakes (indoor/outdoor), crop residue (indoor/outdoor), wood, and LPG. The World Health Organization's 1 hour average CO standard is 35 mg/m^3 or nearly 30.5 ppm, and 60mg/m^3 or nearly 52 ppm (CCOHS, 2014) for an average exposure of half an hour (WHO, 2010). The average CO concentrations during the cooking cycle thus, clearly exceed the 1 hour

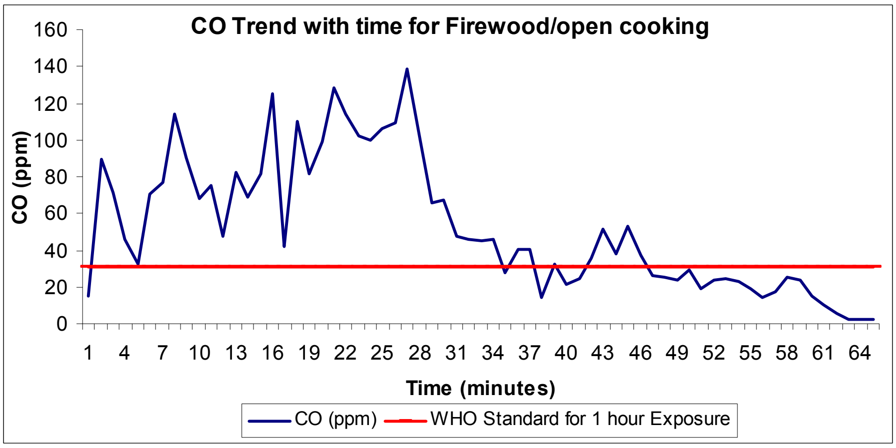
Table 1. Dummy variables for Fuel type.

	Fuel Type			
Variable name	Dung-cake	Crop-residue	Wood	LPG
X_1	1	0	0	0
X_2	0	1	0	0
X_3	0	0	1	0

and half an hour average WHO guidelines in case of CO exposure from cooking with biomass fuels. Earlier studies (Bruce, 2000; Rinne, 2007; Kumar *et al.*, 2012) reported mean 24-hour CO concentrations in homes that use biomass fuel in the range of 2–50 ppm, but the emissions were as high as 500 ppm during cooking. A study by Patel and Riyani (1995) reported indoor air CO levels of 125.7 ppm, 136.2 ppm, 82 ppm, 94.3 ppm and 12.2 ppm during cooking by dung, wood, coal, kerosene and LPG respectively. Similarly, Smith (1991) has estimated that about 38, 17, 5 and 2 g/meal CO is released during the household cooking, using dung, crop residue, wood and kerosene respectively.



(a)



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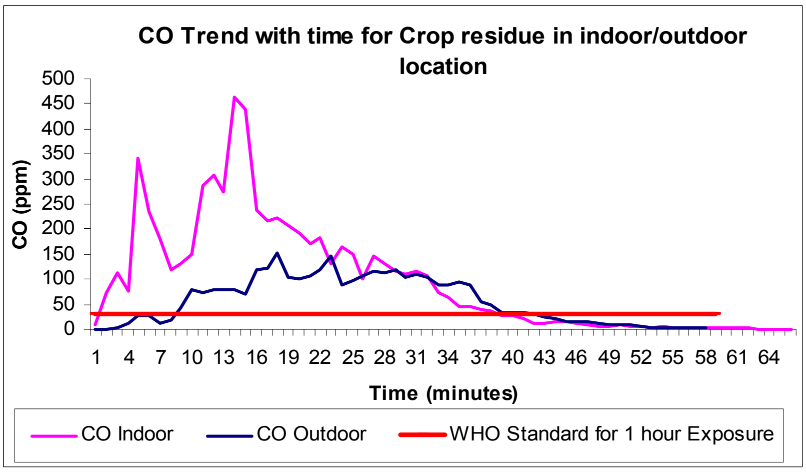
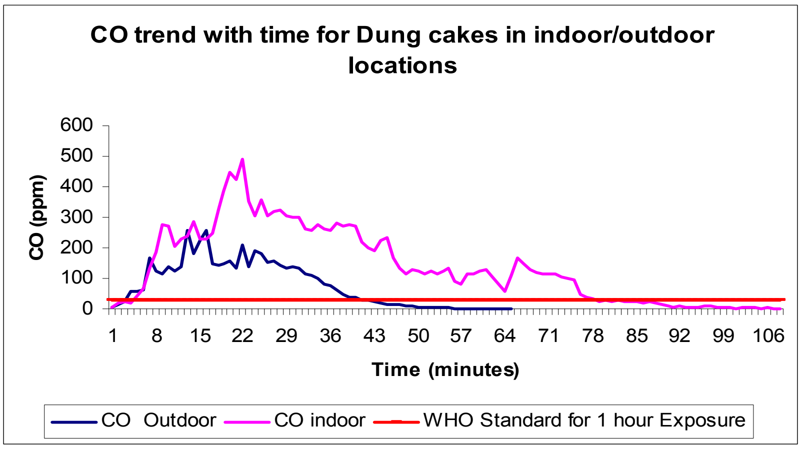


(c)

Fig. 1. (a) Time sequence plot of CO from LPG during the cooking cycle; (b) Time sequence plot of CO from wood burning during outdoor cooking cycle; (c) Time sequence plot of CO from crop residue burning during indoor and outdoor cooking cycle; (d) Time sequence plot of CO from dung-cake burning during indoor and outdoor cooking cycle.



(d)

Fig. 1. *(continued).*

Table 2. Descriptive statistics of average CO levels in breathing zone atmosphere of the cook during cooking cycle.

Fuel/cooking location combination	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
		ppm	ppm	ppm	Lower Bound (ppm)	Upper Bound (ppm)	ppm	ppm
LPG	20	5.21	1.23	0.27	4.63	5.79	3.36	7.50
Wood/outdoor	20	108.68	17.28	3.86	100.59	116.77	65.00	136.90
Crop residue/Semi /open cooking	15	143.37	29.24	7.55	127.18	159.56	90.40	188.73
Crop residue /indoor cooking	5	195.53	38.47	17.21	147.75	243.30	167.00	262.00
Dung cakes /open cooking	13	195.59	28.93	8.03	178.11	213.08	134.94	238.00
Dung cakes /indoor cooking	7	277.85	19.48	7.36	259.83	295.86	254.00	310.00
Total	80	123.67	86.15	9.63	104.50	142.84	3.36	310.00

Table 3. Analysis of Variance results for comparing average CO levels during the cooking cycle among different fuel types.

	Sum of Squares	df	Mean Square	F	Significance
Between Groups	550434.873	5	110086.975	226.755	.000
Within Groups	35926.180	74	485.489		
Total	586361.052	79			

Exhaled Breath CO among the Subjects Exposed to Different Fuel Types

Fig. 2. represents the exhaled breath CO before and after 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 pertaining to all categories of fuel types. But the after cooking exhaled breath CO levels clearly reflect the high levels of CO emitted by different biomass fuels. Whereas no difference is observed between the before and after cooking exhaled breath CO levels in case of LPG users, the 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 case of dung-cake users followed by crop residues users, wood users and LPG users respectively. The results of ANOVA (Table 4.) 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 indicates that the smoke from 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 cook stoves. The breath CO levels of LPG users in the present study are comparable to the levels reported by earlier studies on healthy subjects (Scharte *et al.*, 2000, Cunnigton and Hormbrey, 2002).

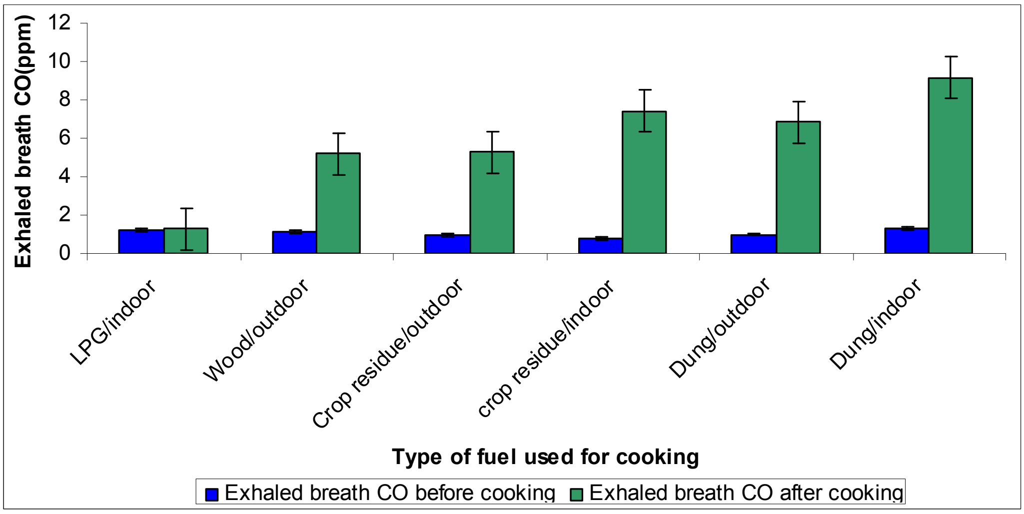


Fig. 2. Exhaled Breath CO of the cooks before and after the cooking cycle.

Table 4. Analysis of Variance results for comparing average exhaled breath CO levels after the cooking cycle among cooks exposed to different fuel types.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	447.117	5	89.423	54.764	.000
Within Groups	120.833	74	1.633		
Total	567.950	79			

Relationship between Average CO during the Cooking Cycle and Exhaled Breath CO

Fig. 3 represents the scatter plot between the average CO concentration to which the subjects were exposed during the cooking cycle and their exhaled breath CO concentration measured after the cooking cycle. It may be observed that there exists a strong positive relationship (correlation coefficient 0.87) between the two variables. The R^2 value of 0.76 reveals that about 76 percent of the variation observed in exhaled breath CO levels may be explained on the basis of average CO concentration during the cooking cycle. Thus, it is seen that exposure to high levels of CO during the cooking cycle, significantly raises the exhaled breath CO levels measured after the cooking cycle. This indirectly indicates towards the presence of a significant level of CO in the blood in the bound form as COHb. A number of studies (Jarvis 1986; Kao and Nanagas, 2005; Thompson *et al.*, 2011) have reported a strong relationship between blood CO levels (i.e., %COHb) and exhaled breath CO.

Multivariate Regression Model for Exhaled Breath CO

Multivariate linear regression was performed for explaining cook's exhaled breath CO with dummy independent variables created in the manner described in methodology section under the head Statistical Analysis. Results of the model fitting exercise are presented in Table 5. It is seen from the table that all the independent variables have significant positive coefficients. The coefficients of the fuel type variables X_1, X_2 and X_3 suggest that the CO levels in exhaled breath increase significantly in case of all the biomass fuels. Further when the cooking takes place indoor (i.e., when $X_4 = 1$), the CO content in the exhaled breath of the subject tends to be more. The adjusted R^2 value of 0.79 indicates that the model is able to explain 79 percent variation observed in the exhaled breath CO of the subjects. It may be noted that the model performance is slightly better than that of the bivariate regression model between average CO concentration during the cooking cycle and exhaled breath CO described earlier under the head Relationship between Average CO during the Cooking Cycle and Exhaled Breath CO.

Thus it may be inferred that it is possible to predict the exhaled breath CO in cooks after the cooking cycle with reasonable degree of confidence without making field measurements of CO in the breathing zone atmosphere of the subject, simply by obtaining the information on fuel-type and cooking location (i.e., indoor/outdoor). Thus, based on the model fitting results, the following model equation is obtained.

$$EXHBCO = 1.3 + 5.57\,X_1 + 3.94\,X_2 + 3.9\,X_3 + 2.22\,X_4 \quad (2)$$

where, EXHBCO represents the exhaled breath CO after the cooking cycle and the dummy variables X_1, X_2, X_3 and X_4 represent the fuel type and cooking location as per the scheme explained earlier.

Assessment of CO Poisoning Symptoms

Studies have shown that exposure to biomass smoke is associated with COHb levels of 2.5–13% against a critical

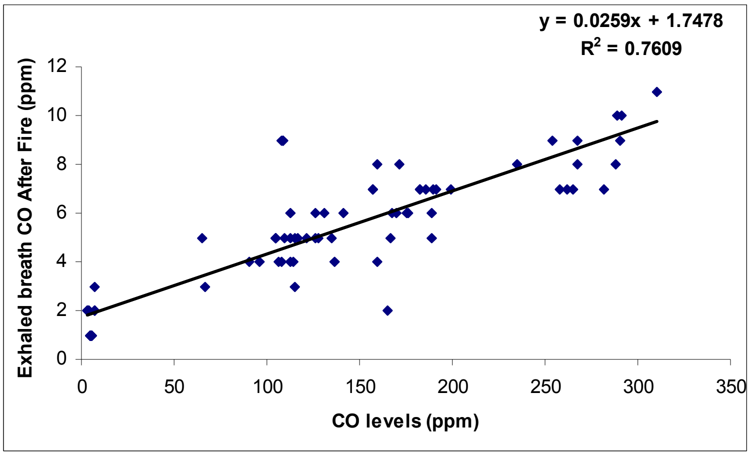


Fig. 3. Scatter plot between the average CO concentration during cooking and exhaled breath CO of the cook after the cooking cycle.

Table 5. Results of the model fitting exercise.

Explanatory Variables	B	Std. Error	t	Significance levels
Constant	1.300	.283	4.594	.000
X1	5.572	.429	12.996	.000
X2	3.944	.415	9.504	.000
X3	3.900	.400	9.744	.000
X4	2.223	.439	5.060	.000

Dependent Variable: EXHBCO. Adj. $R^2 = 0.79$.

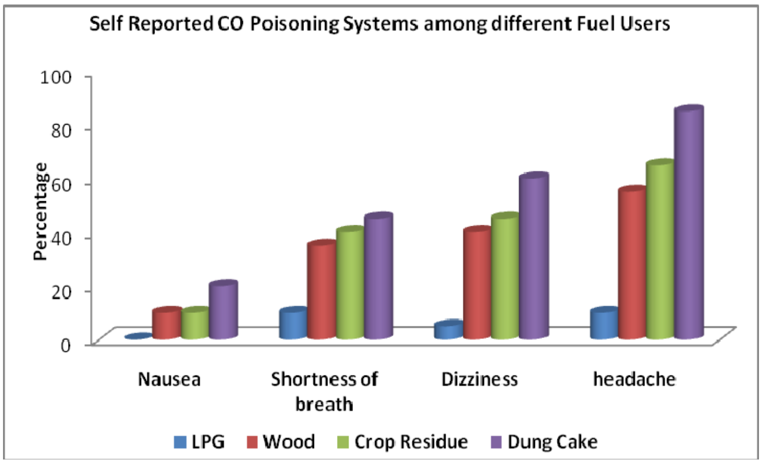
level of 2.5% COHb according to WHO guidelines (Dary *et al.*, 1981; Behera *et al.*, 1988). A study done on wood fired sauna bath users in Guatemalan children and adults showed that measurements of COHb% through exhaled breath were in the range of 1.5%–26% (Lam *et al.*, 2011). In our study COHb% levels were estimated from exhaled breath CO levels of the cook, following the relationship (Eq. (3)) given by Jarvis (1986).

$$COHb\% = 0.63 + 0.16 \times CO_{EB}\ (PPM) \quad (3)$$

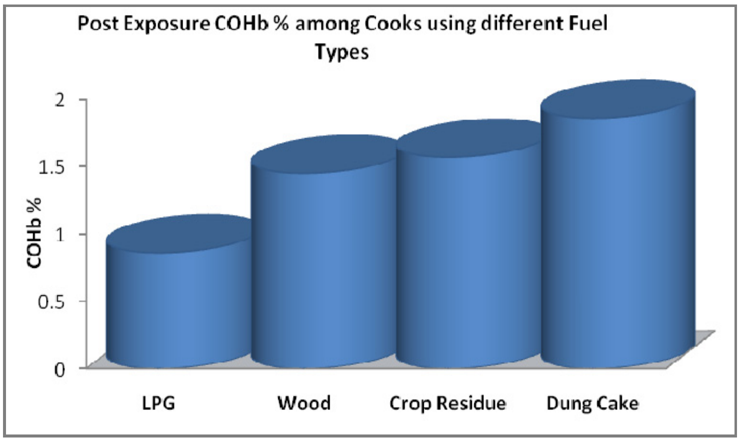
The estimated values of COHb% measured among the cooks exposed to CO emission from LPG, Wood, Crop Residue (outdoor/indoor) and Dung Cakes (outdoor/indoor) in the present study were found to be 0.86, 1.45, 1.48/1.84 and 1.74/2.1 respectively. In a clinical review study, Weaver (1999) suggests that lower level CO exposures can cause headache, malaise, and fatigue. Similarly, Keles *et al.* (2008) report headache, nausea and dizziness to be the most common symptoms of chronic CO poisoning in their study. Based on the information collected through the interview schedule in the present study, the percentage of cooks reporting symptoms such as headache, nausea, dizziness and shortness of breath was obtained (Fig. 4(a)). A comparative examination of the figure reveals that the cooks using biomass fuels report significantly higher percentage of all the four symptoms as compared to those using LPG. Specifically, the percentage of cooks reporting a given symptom increases as we move from LPG, to wood, to crop residue and to dung cake as fuel type. Further, it is worth examining the linkage between percentage of cooks reporting a given symptom and the %COHB levels. Fig. 4(b) represents the variation of average %COHB levels among the cooks using different fuel types. A comparison of Figs. 4(a) and 4(b) reveals that the percentage of cooks reporting a given symptom increases as the COHB% increases. The results thus, complete the linkage between the high CO levels during cooking with biomass fuels; the resultant raised post-exposure exhaled breath CO and COHb% levels, and higher incidence of CO poisoning symptoms among biomass fuel users, thereby clearly establishing the exposure-response relationship among the cooks in the NCR of India.

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 Delhi-NCR 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 regression modeling results suggest that fuel type and cooking location (i.e., indoor/outdoor) may be used as two of the most important determinants of exhaled breath CO in the exposed subjects. The results of the questionnaire survey show that CO poisoning symptoms such as headache, nausea, dizziness and shortness of breath have significantly



(a)



(b)

Fig. 4. (a) Prevalence of CO poisoning symptoms among different fuel users; (b) Post Exposure COHb% levels among the Cooks according to fuel types.

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.

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