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Indoor Particulate Concentration during Biomass burning in Central India

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ABSTRACT

Indoor air particulate (PM) exposure is several folds more dangerous than outdoor air owing to burning of different materials. Burning biomass emits toxic fumes that are found to be associated with numerous health problems such as respiratory diseases, etc. In our study area, approximately 80% of the population of Chhattisgarh state, central India use biomass such as wood, and cow dung as a primary source of domestic energy and therefore require proper study about indoor emission. Thus, the PM10 and associated eight ions i.e. Cl-, NO3-, SO42-, NH4+, Na+, K+, Mg2+ and Ca2+ from the burning of wood and cow dung in indoor in Raipur, Chhattisgarh, central India is investigated. The highest mean concentration of PM10 (17697 µg m-3) and the sum of eight ions, ∑ion8 (38.4 mg m-3), were found from the burning of wood. The indoor concentration of PM10 exceeds the guidelines levels. The wood like Mangifera indica emits the highest concentration of PM10. However, Acacia arabica is found to be acidic in nature. Thus, this result helps us to be aware of the adverse effects of indoor emission from burning. Therefore, the improved models, alternative for energy source and sufficient ventilation are supposed to be recommended option for the future.

Keywords: Indoor air, particulate, ions, wood, cow dung.

Introduction

Biomass is a primary energy source in India.[1] India is an agricultural country with 770 million people (70% population) living in villages or rural area, and depend on various energy sources such as biomass i.e. wood, cow dung etc. for cooking, water heating and lighting in house. About 90% of rural houses and 32% of urban houses use biomass for cooking and only 25% use cleaner gases. In rural India, 62% houses use wood and 14% use cow dung while, 13% use crop residues. Many rural households have energy-inefficient clay-stoves that produce high exposure levels of respirable particulate (PM).[2] Approximately 76% of all global particulate air pollution occurs indoors in the developing world.[3] Indoor concentration of the particulate usually exceed guidelines levels (24 hours mean PM_{10} level of 150 µg m^{-3}) in the range of 300 – 3000 µg m^{-3} and may reach 30,000 µg m^{-3} or more during the periods of cooking.[4] The low income families, who cannot afford modern fuels (like electricity, coal, kerosene, LPG and solar energy), rely on biomass as a primary source of fuel for cooking and water heating purpose. The low income is one of the main barriers of increasing the harmful PM concentration in indoors during biomass burning. The wood and cow dung are the highest contributor fuel in rural areas, while cleaner fuel LPG is the one in urban areas. Therefore, rural households produce greater indoor air pollution than the urban households in India as a result of the use of wood and cow

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dung as major energy sources (Figure 1).[5] This is a challenge for providing convenient fuels until certainty that the energy services is reasonable for the rural poor families. There is a task for policy interventions and government support.[6]

Particulate emitted from wood burning contain OC, BC, nitrate, ammonium, sulphate, organic components and water-soluble potassium etc.[7] K^+ has been used in several cases such as a trace element for the qualitative identification of biomass burning.[8] Nitrogen[9], sulphur[10], and halogen-containing compounds[11] in the PM are the function of fuel composition and combustion conditions. The principal water soluble ions emitted from biomass burning are Cl^-, NO_3^-, SO_4^{2-}, NH_4^+ and K^+. Cow dung emits numerous amounts of NO, NH_3, SO_2 and CH_3Cl because of their high N, S and Cl content.[7] It was reported that water soluble ions such as sulfate, nitrate and other acid rain related pollutants have severe effects on human health.[12] The continuous use of wood for cooking is an unavoidable issue in developing countries and also in India, owing to its adverse health effect.[13,14]

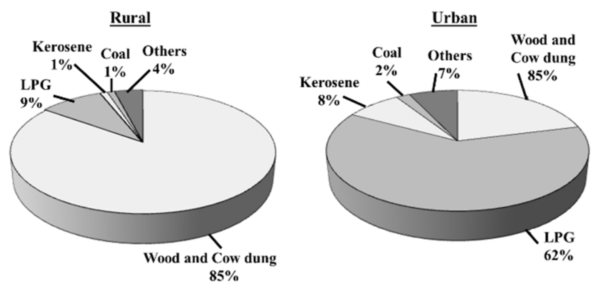

Fig. 1 Distribution of cooking fuels for rural and urban households in India (NSSO, 2010, Ref. 4).

Women and children are exposed especially to respiratory infections i.e. acute and chronic respiratory diseases (particularly obstructive pulmonary disease) caused by indoor air pollution, because they spend most of their time at home during fuel burning. The health problems include acute lower respiratory infections in children up to 5 years, chronic obstructive pulmonary disease in adults, tuberculosis, asthma, cataracts, among others .[15,16] In developing countries, indoor air pollution is more than 5-times greater than the outdoor air pollution causing adverse health effects.[17,18] The kitchen used for cooking in various Indian households is found to be poorly ventilated, and approximately one-half of all households do not have a separate kitchen. Virtually all houses have no proper ventilation and chimney.[16]

Chhattisgarh is an agricultural state of central India. The population of this state has been ranked as the 16th top most state in India. Remarkably, more than 80% of the population live in rural area and their major work is dependent on agriculture. Nearly everyone uses wood and cow dung for cooking and for other purpose. Due to several adverse effects of indoor air during burning of wood and cow dung, evaluation of the PM and ions concentration is necessary in our study. Therefore, the indoor PM and ions during burning of wood and cow dung in Raipur, Chhattisgarh, central India is investigated. This study tried to examine the PM and ions during burning of indoor materials and that they may be valuable for evaluating future harmful effect.

Materials and Methods

The indoor burning materials i.e. commonly used different type of wood (n = 5) and cow dung (n = 1) were selected for the current study. In India, numerous human culture and medicinal practices are influenced by plants i.e. Tamarindus indica; it is used as an energy source for cooking, water heating etc. in houses: Mangifera indica; it is commonly used to worship the god in Puja or Hawans by burning the stem: Azadirachta indica; it is used as an energy source, medicinal plants and to drive away mosquitoes by burning its leaves: Ipomea nil and Acacia arabica are used as an energy source. The indoor environments (a standard room (3x2x3 m^3) equipped with one door and one window (1x1 m^2)) i.e. kitchen using homemade clay-stove for wood and cow dung burning was chosen for collection of particulate (PM_{10}). A Partisol Model 2300 sequential speciation air sampler (Thermo Fisher Scientific, USA, 10 L min^{-1}) was used for collection of PM_{10} on 47-mm quartz fiber filters

(Whatmann, QMA) housed in molded filter cassettes, in the indoor environments for the duration of 1 hrs. The air sampler was installed at the ground level and operated in flow rates of 10 L min^{-1}. Always at least one blank filter was used to correct the background values. The filters were heated to 600˚C for 6 hrs before exposure so as to reduce the carbon blank values. The filters were weighted by employing the Mettler Toledo balance type - AG245 and placed in the sampler and run for the duration of the burning process. In order to eliminate moisture contents from the loaded filters, it was heated up to 50˚C for 6 hrs. The filters were finally weighted to measure the particulate mass load. The mass of the particulate in the air was calculated by dividing the aerosol mass with the volume of the air passed.[19]

Additional 15 mL of de-ionized water (0.054 µS cm^{-1}) was used to extract PM content followed by sonication for 15 min and about 24 hrs heating at 60ºC. After filtration of the extract using tracer filters (0.45 µm of pore size), about 200 µl of aliquot was added into the ion chromatograph. The ion chromatograph (DX120, Dionex, USA) equipped with anion separation column (AS9-HC, 250x4 mm), cation separation column (CS12A, 250x4 mm) and conductivity detector was used to analyze the ions. The eluents, 9 mM Na_2CO_3 (1.4 mL min^{-1}) and 20 mM methane sulfonic (0.8 mL min^{-1}) were used for leaching of the anion and cation, respectively. In order to evaluate the soluble ion content of the samples, a standard (AR, E. Merck) was employed for the preparation of the calibration curves. The laboratory blank was used to assess possible contaminations.

The emission flux of PM_{10} was determined by burning the materials in a closed chamber (0.5x0.5x0.5 m^3) consisting of wood equipped with the exhaust fan and UC Davis (USA) portable air sampler (Figure 2). The sampler was mounted on the chamber. Two gram of each material was used for the burning. The burning was carried out till the complete burning of the materials with concurrent collection of the PM_{10} over the quartz filter paper (47 mm). Likewise, the sample blank (i.e. without collection on filter) was done for the correction. The PM_{10} mass was weighted out, and the flux was evaluated by dividing the PM_{10} mass with the amount of the burnt material. The flux for the PM_{10} was calculated by using the following equation (1):

$$PM_{flux}=PM_m/W \qquad (1)$$

where, PM_m and W r represent the mass of PM_{10} in the filter and the amount of the burning materials. The flux for the ions associated with the PM_{10} was calculated by applying the following equation (2):

$$A_{flux}=PM_{flux}\times F \qquad (2)$$

where, A_{flux}= Fluxes of ion in the PM_{10}, F = Ionic fraction in the PM_{10}.

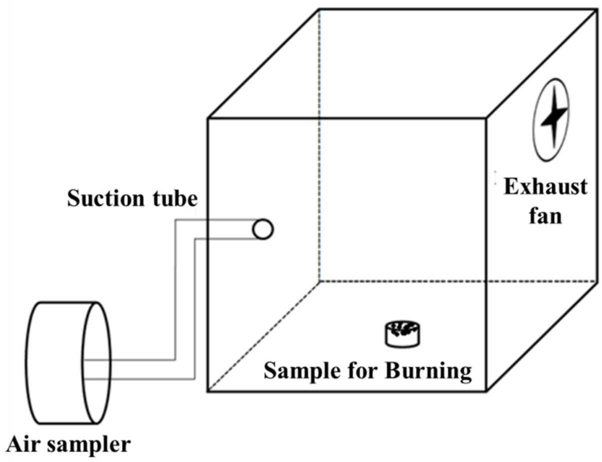

Fig. 2 A closed chamber (0.5x0.5x0.5 m^3) equipped with the exhaust fan and UC Davis (USA) portable air sampler**.**

Results and Discussion

The concentration of PM_{10} of the indoor environments during burning of five types of wood (n = 5) and cow dung (n = 1) is given in Table 1. The PM concentration of wood and cow dung was found to be 17697 and 7768 µg m^{-3}, respectively. In this study, the highest PM concentration was observed in the wood than in cow dung; which indicate that the use of wood as a cooking fuel has been a major factor of increasing PM concentration in indoor environment. Evidently, higher PM concentration of wood and cow dung also demonstrates that they are more harmful fuels compared to the other cleaner fuels like LPG.

Also, the PM concentration of wood and cow dung was found to be several times higher than the guidelines levels i.e. 150 µgm^{-3} for 24 hours. India is a religious country and they burn up wood and cow dung as an energy source as well as also for worship purposes of indoor environments. Among the wood materials tested, the highest PM concentration was observed with *Mangifera indica* (24035 µg m^{-3}) that is used for both purposes i.e. as an energy source as well as for worship; indicating that it is a more harmful material than the other tested materials. *Mangifera indica* is commonly used to worship the god because, Hindu religion in India believes that the god bless good health and wealth to human life by burning stem of this plant.[20] Some studies in India and other developing countries reported high PM concentration during burning of wood and cow dung in the indoor environments.[21-27] The direct comparison of PM between this study and other studies is difficult owing to the use of different wood materials, and different burning and monitoring techniques. Lohani et al. found that PM_{10} concentration on wood burning houses is 2 times greater than in LPG and kerosene using houses in Nepal which implies that wood or biomass burning is a more dirty fuel than the LPG and kerosene.[15]

Table 1 Concentration of PM_{10} and ions in PM_{10} in indoor air, µg m^{-3}

Sample No.	Materials	PM_{10}	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
W1	*Tamarindus indica*	19836	6.2	3.2	3.6	0.2	3.8	1.7	0.5	4.0
W2	*Mangifera indica*	24035	19.8	7.1	8.0	10.4	1.8	16.4	0.5	4.5
W3	*Azadirachta indica*	15015	8.2	2.7	4.8	0.1	1.8	8.5	0.3	2.6
W4	*Ipomea nil*	10490	4.4	3.6	5.4	0.2	2.4	2.6	0.6	2.7
W5	*Acacia arabica*	19107	17.9	6.8	4.7	0.3	5.4	10.7	0.4	3.0
CD6	Cow dung	7768	6.9	2.5	1.9	0.1	1.8	4.3	0.1	0.9

The PM_{10} samples derived from burning of wood and cow dung were examined for the determination of eight ions i.e. Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Mg^{2+} and Ca^{2+}, Table 1. The percentage contribution of ions to the sum of eight ions ($\sum ion_8$) is presented in Figure 3. The mean concentrations of ions for wood (38.4 µg m^{-3}) burning were found to be higher than the cow dung (18.5 µg m^{-3}). Among the wood materials, the highest $\sum ion_8$ concentration was observed with *Mangifera indica* (68.5 µg m^{-3}) and the second highest concentration was marked with *Acacia arabica* (49.2 µg m^{-3}). Both wood materials are commonly used as an energy source in this study area due to their great availability and *Mangifera indica* is also even used for worship purpose. Likely to the high PM concentration, *Mangifera indica was* also found to be higher in ionic concentration, which indicates its great harmfulness for indoors than the other wood materials. Almost similar concentration trend of each ion was observed with the wood and cow dung i.e. $Cl^- > K^+ > SO_4^{2-} > NO_3^- > Na^+ > Ca^{2+} > NH_4^+ > Mg^{2+}$. Among all ions, the highest concentration was observed with Cl^- for both materials i.e. wood (11.3 µg m^{-3}) and cow dung (6.9 µg m^{-3}). The second dominant ions was found to be K^+ and its concentration for wood and cow dung were 8.0 µg m^{-3} and 4.3 µg m^{-3}, respectively. The reported work also shows that Cl^- is the most abundant inorganic species in the PM that originated from biomass fuel burning.[28] K^+ is the main component of any kind of biomass burning[8], and often used as a marker for biomass burning; however the second highest concentration of K^+ ion aside the first was found in this work. The other study conducted in outdoor in Raipur, central India and other Indian sites also reported lower concentration of K^+ ion in the PM.[29,30]

The other work has also reported the higher fraction of K^+ and Cl^- in PM, which is comparable with our study.[31,32] The concentration of ions was compared with the reported work in India and other region, and it was found that the different trend of ions due to different soil quality, weather, ground water quality etc., can affect the chemical composition of species of different biomass fuel used in a region. Singh et al. have reported the concentration trend of ions i.e. SO_4^{2-} > NO_3^- > Ca^{2+} > Cl^- > K^+ >Na^+ > Mg^{2+} > NH_4^+.[33] In $\sum ion_8$,

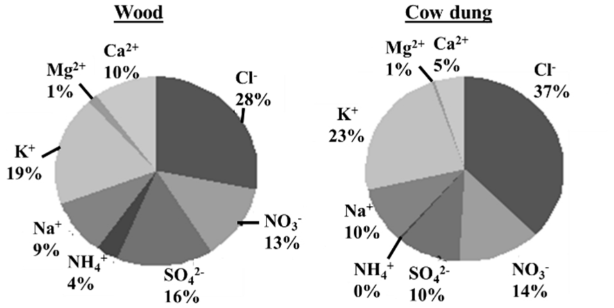

Fig.3 Percentage contribution of ions to the $\sum ion_8$ during burning of materials i.e. wood and cow dung.

the highest anionic contribution was observed with both materials i.e. 56.4% for wood and 61.6% for cow dung. The cationic concentration was found to be 43.6% and 38.8% for wood and cow dung, respectively. The highest anionic contribution was observed with cow dung as a result of high level of Cl^- and NO_3^- ions thus indicating that cow dung is a more acidic material than wood.

The ion equilibrium calculations were measured to observe the acid-base equilibrium of ions particulate in the burning emissions from indoor and are listed in Table 2.[34] Estimation of charge equilibrium between anions and cations was measured by converting the concentrations into ion micro equivalents as the following equation (3):

Anion micro equivalents = $Cl^-/35.5 + NO_3^-/62 + SO_4^{2-}/48$

Cation micro equivalents=$NH_4^+/18 + Na^+/23 + K^+/39 + Mg^{2+}/12 + Ca^{2+}/20$ (3)

The mean particulate equivalent concentration ratio of the ∑anion to ∑cation in the wood and cow dung was found to be 0.77 and 0.90, respectively. The equilibrium concentration ratio of both materials shows that the anions were balanced with the cations. Owing to higher anionic concentration of cow dung, it shows that it has more acidic indoor environment than wood burning. Among the wood materials, the *Acacia arabica* was observed to be acidic in nature and their particulate equivalent concentration ratio was 1.01, indicating that its burning can create harmful indoor acidic environment.

Table 2 Particulate equivalent concentrations of ions, µEq

Sample No.	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	∑anion	∑cation	∑anion/∑cation
W1	0.17	0.05	0.08	0.01	0.17	0.04	0.04	0.20	0.30	0.46	0.65
W2	0.56	0.11	0.17	0.58	0.08	0.42	0.04	0.23	0.84	1.35	0.62
W3	0.23	0.04	0.10	0.01	0.08	0.22	0.03	0.13	0.37	0.47	0.79
W4	0.12	0.06	0.11	0.01	0.10	0.07	0.05	0.14	0.29	0.37	0.78
W5	0.50	0.11	0.10	0.02	0.23	0.27	0.03	0.15	0.71	0.70	1.01
CD6	0.19	0.04	0.04	0.01	0.08	0.11	0.05	0.05	0.27	0.30	0.90

Majority of the population of our study area live in rural and are commonly using wood and cow dung for household purpose. The construction of numerous kitchen in Chhattisgarh state was poorly ventilated and have shortage of chimney. As a result, the level of toxic contaminants is very high in indoor air resulting in serious health issues.

The emission flux is dependent on two factors i.e. the type of material and their burning condition. The PM_{10} emission flux for wood and cow dung was found to be 5.38 and 10.67 g kg^{-1}, respectively, Table 3. The emission flux in the case of cow dung is remarkably higher, probably due to its smouldering burning. This smouldering fire enhances the rate of carbon emission and the emission is associated with particulate matter.[35] Higher PM emission of cow dung may be observed in the pyrolysis process under low temperature[36], whereas, wood undergoes all three types of burning phases (ignition, flaming and smouldering) than cow dung[37] resulting in a remarkably lower PM emission. Saud et al. reported that the PM emission in wood and cow dung is 4.34 g kg^{-1} and 16.26g kg^{-1}.[38] Furthermore, Saud et al. measured 4.68 g kg^{-1} and 15.68 g kg^{-1} PM emission for wood and cow dung, respectively. The above study was found to be very close to our results.[39] The emission flux, 5.38 g kg^{-1} obtained from wood burning is consistence with reported results as 5.66 g kg^{-1}.[40,41] However, another study found the same fact that cow dung (5.37 g kg^{-1}) has higher emission flux than wood (1.69 g kg^{-1}), owing to its smouldering fire. The emission flux of four different woods which ranged from 1.12-2.89 g kg^{-1} was reported in Portugal and is lower compared to the present investigation, due to different chemical composition of wood.[42]

The emission flux of $\sum ion_8$ for cow dung (52.84 g kg^{-1}) was found to be 8-folds higher

Table 3 Emission flux of PM_{10} and ions, g kg^{-1}

Sample No.	PM_{10}	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
W1	3.12	0.81	0.31	0.31	0.03	0.62	0.22	0.06	0.62
W2	1.62	1.01	0.32	0.32	0.49	0.10	0.81	0.02	0.16
W3	1.95	0.16	0.06	0.10	0.002	0.04	0.16	0.006	0.58
W4	10.78	2.26	2.16	3.23	0.11	1.08	1.08	0.32	0.12
W5	9.41	4.52	1.88	0.94	0.09	0.94	2.82	0.09	0.75
CD6	10.67	21.35	7.47	5.34	0.21	5.34	10.67	0.32	2.14

than wood (5.94 g kg^{-1}), which may be due to their burning in smouldering fire, Table 3. Higher ionic flux is associated with the PM emission. The ions emission flux obtained from cow dung is higher and similar as compared to other reports.[34,39] The anion emission trend of the current study has also been compared with other reports[43-45], and it was found that the soil quality, weather, ground water quality etc. can affect the chemical composition of species of different wood used in a region[39] and, therefore, the difference was found with the emissions.

The correlation concentration between PM_{10} and ions of wood burning is shown in Table 4.

The reported correlation values >0.70, are highlighted in bold (see Table 4). The analysis of correlation values of K+ and Cl- (r = 0.84) illustrates their origin from same source. The reported study also indicated higher correlation between K^+ and Cl^- by biosmoke and derived K^+ should exist in the form of KCl.[46] However, another reported work demonstrates that K^+ is associated with the particulate that are generated from biomass burning.[47] Therefore, it can be concluded that they were generated from the same sources (wood burning) and should exist in the form of KCl.

Table 4 Correlation coefficient of PM_{10} and ions from burning of wood materials

	PM_{10}	Cl^-	NO_3^-	SO_4^{2-}	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
PM_{10}	1								
Cl^-	0.58	1							
NO_3^-	0.43	0.88	1						
SO_4^{2-}	0.15	0.38	0.21	1					
NH_4^+	0.48	0.46	0.57	0.84	1				
Na^+	0.02	0.05	0.01	0.29	0.19	1			
K^+	0.42	0.84	0.14	0.6	0.61	0.03	1		
Mg^{2+}	0.02	0.05	0.1	0.05	0.04	0.01	0.11	1	
Ca^{2+}	0.73	0.21	0.99	0.21	0.57	0.01	0.14	0.1	1

Conclusion

In the present study, approximately 80% of the population of Chhattisgarh state live in rural area and depend upon biomass i.e. wood and cow dung for cooking and other purpose. The wood like *Mangifera indica* is used for both energy source as well as to worship the god in indoors and it emits higher concentration of particulate which results in adverse health effect such as respiratory diseases, eyes infections, etc. Majority of the people use *Acacia arabica* in the form of energy sources due to its greater availability and its acidic appearance in nature. However, the higher emission flux was observed with cow dung than wood. Hence, to improve the quality of indoor air, some recommended options should apply in future such as cleaner source of energy (LPG), sufficient ventilation to exhaust toxic gases and installation of improved models. The outcome of our investigation is for people to be aware of the adverse effects of indoor emission and also to use cleaner fuel and to prefer improved model for better indoor environment.

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