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CARBONACEOUS PARTICULATE CONCENTRATION DURING INDOOR BURNING

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Abstract: **Wood, crop residue, cow dung is a primary cooking fuel for a large majority of Indian households. Similarly, the fuming materials i.e. incense and mosquito coil are also widely used in indoor environments. Their incomplete combustion generates particulate matter of a complex chemical composition with high potential environmental and health risks. There are an estimated 1.8 million deaths per year due to toxic EC and other indoor air pollutants. Therefore, carbonaceous particulate (EC and OC) in PM_{10} during burning of materials i.e. fuels (i.e. LPG (liquefied petroleum gas), kerosene, coal, cow dung, wood and crop residues), incense and mosquito coil in September, 2013 in typical indoor environments at Raipur, Chhattisgarh, India is measured in the present work. The EC concentration was found in the following order: wood kerosene crop residues cow dung incense coal mosquito coil LPG; OC was in the following order: wood crop residues incense cow dung coal mosquito coil kerosene LPG. The highest OC concentration was observed in all tested materials except for kerosene and camphor, shows OC is a predominant contributor to the total carbon. The highest total carbon was observed during wood burning, indicates the harmful impact to the women and children who spent more time in indoor environment i.e. kitchen. The incense and mosquito coil were also found a significant contributor of carbonaceous particulates. The OC/EC ratios and contribution of SOC are discussed.**

Key words: **Elemental carbon · organic carbon · OC/EC ratios · secondary organic carbon**

I. INTRODUCTION

In developing countries, biomasses, agricultural residues and charcoal are the primary source of domestic energy [1]. About half of the world households still use solid fuels such as wood, coal, cow dung and crop residues, ranging near 80% in the developing countries i.e. China, India and Sub-Saharan Africa [2]. Biomass burning in the indoor environments by using conventionally homemade clay-stoves, called 'Chulha' for cooking food, are the main cause of the indoor air pollution because of incomplete combustion due to the energy-inefficient clay-stoves and also due to the residual water content in the biofuel [3]. In the energy ladder, firewood, cow dung and crop residues are inexpensive fuels, and readily available alternate energy sources as compared to electricity and LPG. The incomplete combustion of these materials generates particulates (PM), elemental carbon (EC) and organic carbon (OC), polycyclic aromatic hydrocarbons (PAH), carbon monoxide (CO), benzene, isoprene, elements, various salts, etc. in the indoor environment [4].

The incense materials are used for worship as well as to fragrance the indoor environments in the Asia for centuries. The incomplete combustion produces heavy incense smoke which is causing indoor air pollution. Burning of incense would emit a variety of toxic chemicals. For example, incense was discovered to be a significant source of polycyclic aromatic hydrocarbons (PAHs), carbon monoxide, benzene, isoprene and particulates [4-5]. The mosquito coils are fumed to repel mosquito in Asia and to limited extent in other parts of the world, including the United States. They contribute significantly to the indoor air pollution [6]. Liu and Sun, [7] has investigated emissions of organic compounds from mosquito coil smoke i.e. allethrin, phenol, benzene, toluene and xylene, as well as aromatic and aliphatic hydrocarbons.

Carbonaceous particulate are usually classified into elemental carbon (EC) and organic carbon (OC). Elemental carbon emits predominantly from incomplete combustion process, and it has been used as a tracer for primary organic carbon (POC) [8]. Organic carbon consists of POC, which is emitted in particulate form, and secondary organic carbon (SOC), which is formed secondarily through atmosphere chemical reactions. Generally, the EC and OC contribute 10% to 50% to atmospheric PM mass [9-10]. No simple analytical methods are available to quantify POC and SOC. Some methods have been used to estimate the SOC [8,11-13].

The EC is considered to be the second largest contributor of global warming next to CO_2 in terms of direct forcing [14]. EC is also a potential transporter of toxic compounds into human and animal respiratory systems. OC represents a large variety of organic compounds which can be classified into general compounds classes such as aliphatic, aromatic compounds, acids and numerous unidentified compounds [15]. Studies show that OC contributes to visibility reduction and may contain carcinogenic compounds harmful to human health. In developing countries over 1.8 million people die

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every year from exposure to elemental carbon and other emissions from indoor burning [16].

Carbonaceous particulates i.e. EC and OC), as important components of smoke from indoor burning materials i.e. fuel, incense and mosquito coil, not only contributed to marked dreadful conditions of indoor environments but also have adverse effects on human health due to toxic organic compounds, such as polycyclic aromatic hydrocarbons (PAHs) [5. 7, 17]. Therefore, it is essential to investigate emissions of smoke from indoor burning. This study first time reporting the carbonaceous particulate in indoor PM_{10} during burning of materials i.e. fuels (i.e. LPG, gasoline, diesel, kerosene, coal, cow dung, wood and crop residue), incense (i.e. incense sticks, dhoop, lobhan powder and camphor) and mosquito coil in September, 2013 at central India, Raipur, Chhattisgarh that may be useful to estimate future harmful impact from carbonaceous particulates during indoor burning of different materials.

II. MATERIALS AND METHODS

STUDY AREA

Chhattisgarh is an agricultural state of central India. It is the 16th most-populated state of the India. About 80% of the population of the state is rural and the main livelihood of the villagers is agriculture. Most of the people use biomass i.e. wood, crop residues and cow dung as a primary fuel for cooking and other purposes. Due to tropical climate, almost similar type of indoor environments is allocated all over the India. Therefore, Raipur city, Chhattisgarh, India is selected for the present work.

MATERIALS

The main three group of indoor burning materials commonly used in chosen area i.e. fuel (n = 33), incense (n = 10) and mosquito coil (n = 4) is selected for the study. Gaseous to solid fuel are used for the present work i.e. LPG, kerosene, coal, cow dung, wood (i.e. *Tamarindus indica, Mangifera indica, Azadirachta indica, Aegle marmelos, Ficus bengalensis, Butea monosperma, Eucalyptus, Datura alba, Nerium indicum, Tamarindus indicum, Calotropis procera, Withania somnifera, Acacia Arabica, Ipomea nil, Ficus religiosa, Ocimum bacilicum, Shorea robusta, Cinnamomum L., Garcinia indica*) and crop residues (i.e. *Vigna mungo fodder, Vigna mungo husk, Oryza sativa fodder, Oryza sativa husk, Triticum S. fodder, Lens E. husk, Coriandar C. husk, Lin husk*). The majority of Indian uses traditional fuels as a primary fuel. Traditional fuels include wood, charcoal, dung cake, and crop residues, while modern fuels include electricity, coal, kerosene, LPG and today even solar energy [18]. India is a religious country and they use different types of incense i.e. incense stick, dhoop (log), camphor, lobhan powder to worship the God as well as to fragrance the indoor environments. Incense paste is rolled around a bamboo stick, is one of the main forms of incense in India. Mosquito coil is widely used in India because they have mosquito problem due to high temperature increasing the breeding of mosquitoes. Biomass is a base material of these two products i.e. incense and mosquito coil and rest part of material is an organic and inorganic ingredients.

COLLECTION OF PM

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 biomass, coal and cow dung burning, steel stove for kerosene and bedroom for incense and mosquito coil burning was selected for collection of particulates (PM_{10}). Air sampler (Thermo Scientific Partisol, USA) 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 at flow rates of 10 l min^{-1}. Always at least one blank filter was used to correct for the background values. The filters were heated to 600˚C for 6 hrs prior to exposure for reducing the carbon blank values.

The weighted filters were placed in the sampler and run for the duration of the burning process. The loaded filters were dismounted and heated up to 50˚C for 6 hrs to remove the moisture contents. The filters were transferred into the desiccators, and finally weighted to measure the particulate mass load and used for the analysis of carbon.

ANALYSIS OF CARBONS

A standard thermal method [19-20] was used for analysis of black or elemental carbon (BC or EC) and organic carbon (OC) content by measuring the formation of CO_2 when heating (in pure helium) and burning (in pure oxygen) the quartz filter samples. At least 3 pieces (d = 11 mm) from each of the sample and blank filters were punched out and analyzed. The filter pieces were feed into a stainless steel cylinder which was placed in an oven purged with pure helium. The temperature of the oven was increased stepwise from room temperature to 350˚C and then to 650˚C. An oxidizing catalyst converted all carbon into CO_2 which was measured with a non-dispersive infrared detector (NDIR, Rosemount). The fraction volatilized up to 650˚C in pure helium was defined as organic carbon fraction (OC), and the fraction volatilized in a second step at 650˚C in pure oxygen was defined as black carbon (BC). However, the sum of OC and BC contents in this work was considered as total carbon (TC).

EMISSION FLUX MEASUREMENT

The emission fluxes were measured for three types of fuel i.e. coal, cow dung and wood, and incense and mosquito coil. The flux of PM_{10} was determined by burning the materials in a closed chamber (0.5x0.5x0.5 m^3) made up of wood equipped with the exhaust fan and UC Davis (USA) portable air sampler, Fig. 1. The sampler was mounted in the chamber. Two gram of each material was taken for the burning. The burning was carried out till the complete burning of the materials with simultaneous collection of the PM_{10} over

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the quartz filter paper (47 mm). Similarly, the sample blank (i.e. without collected on filter) was carried out for the correction. The PM_{10} mass was weighted out, and the flux was evaluated by dividing the PM_{10} mass with amount of the material burnt. The flux for the carbon associated to the PM_{10} was calculated by using the following equation (1):

$$A_{flux} = PM_{flux} \times F \quad (1)$$

Where, A_{flux} = Fluxes of EC and OC in the PM_{10}; PM_{flux} = PM_m/W, PM_m and W denote the mass of PM_{10} in the filter and amount of the materials for burning; F = EC and OC fraction in the PM_{10}.

III. RESULTS AND DISCUSSIONS

CONCENTRATION OF CARBONS

The carbonaceous particulates i.e. EC and OC were quantified in the PM_{10} emitted from the different burning materials i.e. fuels (i.e. LPG, kerosene, coal, cow dung, wood and crop residues), incense and mosquito coil in indoor environments. The sum of total concentration of EC and OC is considered as total carbon (TC) in the present work. The EC and OC concentration and their contribution to the PM_{10} and TC in the indoor environments is summarized in Table 1 and 2.

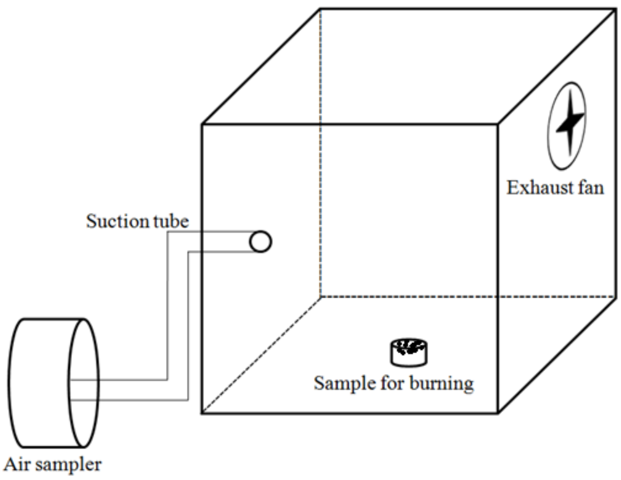

Fig. 1. A closed chamber (0.5x0.5x0.5 m^3) equipped with the exhaust fan and UC Davis (USA) portable air sampler.

Among the fuels (i.e. LPG, kerosene, coal, cow dung, wood and crop residues), the highest concentration of EC (1920±353 µg m^{-3}) and OC (8452±1704 µg m^{-3}) was observed for wood (n = 19), contributing, on averaged, 12.2±1.7% and 52.3±7.2% to the $PM_{10,}$ and 20.2% and 79.8% to the TC, respectively. Similarly, the lowest concentration of EC (41±18 µg m^{-3}) and OC (126±8 µg m^{-3}) was marked for LPG (n = 2), contributing, on averaged, 5.1% and 16.7% to the PM_{10}, and 24.1% and 75.9% to the TC, respectively. The highest concentration of EC (1642 µg m^{-3}) was observed compare to the OC (247 µg m^{-3}) for kerosene, contributing 53.0% to the PM_{10} and 86.9% to the TC, indicate it is a black smoke fuel and more contributor of global warming than the other fuel. Begum et al., [21] has reported the EC (27.2±8.3 µg m^{-3}) concentration for LPG and range of mean EC (207-220 µg m^{-3}) and OC (477-506 µg m^{-3}) for wood was found to be lesser than the present work.

TABLE 1. CONCENTRATION OF EC, OC AND OC/EC RATIOS IN PM_{10} IN INDOOR AIR, µg m^{-3}

Sample type	Materials	EC	OC	TC	OC/EC
LPG (n = 2)	LPG	31	121	152	3.9
	LPG	50	130	180	2.6
Kerosene (n = 1)	Kerosene	1642	247	1889	0.2
Coal (n = 2)	Coal	837	3334	4171	4.0
	Coal	451	842	1293	1.9
Cow dung (n = 1)	Cow dung	798	3327	4125	4.2
Wood (n = 19)	*Tamarindus indica*	2392	11612	14004	4.9
	Mangifera indica	2489	12629	15118	5.1
	Azadirachta indica	1577	9534	11111	6.0
	Aegle marmelos	3012	11800	14812	3.9
	Ficus bengalensis	1877	9744	11621	5.2
	Butea monosperma	1322	5048	6370	3.8
	Eucalyptus	883	2597	3479	2.9
	Datura alba	93	148	241	1.6
	Nerium indicum	1276	4448	5724	3.5
	Tamarindus indicum	2155	6755	8910	3.1
	Calotropis procera	1267	8553	9820	6.8
	Withania somnifera	2088	7561	9649	3.6
	Acacia arabica	3068	9390	12458	3.1
	Ipomea nil	1452	5440	6892	3.7
	Ficus religiosa	2367	12187	14554	5.1
	Ocimum bacilicum	2572	14865	17437	5.8
	Shorea robusta	2683	12378	15061	4.6
	Cinnamomum L.	2583	7075	9658	2.7
	Garcinia indica	1327	8823	10150	6.6
Crop residues (n = 8)	*Vigna mungo fodder*	3013	17786	20799	5.9
	Vigna mungo husk	265	526	791	2.0
	Oryza sativa fodder	726	3474	4200	4.8
	Oryza sativa husk	1619	9530	11149	5.9
	Triticum S. fodder	2344	8001	10345	3.4
	Lens E. husk	1603	11047	12650	6.9
	Coriandar C. husk	608	6891	7499	11.3
	Lin husk	901	4671	5572	5.2
Incense (n = 10)	Mumtaj	984	7878	8862	8.0
	Krishna	995	7030	8025	7.1
	Lubhan	979	8001	8980	8.2
	Parivar 100	291	1932	2223	6.6
	Bharat Darshan	198	2280	2478	11.5
	Silver kobra	1504	8132	9636	5.4
	Singarpuri	186	1097	1283	5.9
	Dhoop	1371	7110	8481	5.2
	Lobhan powder	115	2574	2689	22.4
	Camphor	1138	970	2108	0.9
Mosquito coil (n = 4)	Hit	71	362	433	5.1
	Jet	58	320	378	5.5
	Mortein	82	453	535	5.5
	Tartoise	60	377	437	6.3

However, the mean concentration of EC and OC for the incense (n = 10) was 776±327 µg m^{-3} and 4700±1949 µg m^{-3}, contributing, on averaged, 10.0±5.8% and 51.9±9.6% to the $PM_{10,}$ and 16.0% and 84.0% to the TC, respectively. The highest concentration of EC (1138 µg m^{-3}) was observed compare to the OC (970 µg m^{-3}) for camphor, contributing 35.5% to the PM_{10} and 54.0% to the TC, indicate it is a black

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smoke material and more contributor of global warming than the other incense.

Whereas, the mean concentration of EC and OC for mosquito coil (n = 4) was 68±11 and 378±55, contributing, on averaged, 6.0±0.8% and 33.3±2.9% to the $PM_{10,}$ and 15.2% and 84.8% to the TC, respectively. Among the fuming materials i.e. incense and mosquito coil, the highest carbon concentration was observed for the incense. The Wang et al., [5] has presented range of mean EC (22.8-74.0 µg m^{-3}) and OC (139.8-4414.7 µg m^{-3}) for incense and similarly, Wang et al., [22] has reported range of mean EC (46-47 µg m^{-3}) and OC (250-770 µg m^{-3}) for incense was observed to be lower than the this work.

TABLE 2. CONTRIBUTION OF EC AND OC TO THE PM_{10} AND TC, %

Sample type	Materials	PM_{10}		TC	
		EC	OC	EC	OC
LPG (n = 2)	LPG	5.2	20.3	20.4	79.6
	LPG	5.0	13.1	27.8	72.2
Kerosene (n = 1)	Kerosene	53.0	8.0	86.9	13.1
Coal (n = 2)	Coal	14.0	55.9	20.1	79.9
	Coal	14.4	27.0	34.9	65.1
Cow dung (n = 1)	Cow dung	10.3	42.8	19.3	80.7
Wood (n = 19)	*Tamarindus indica*	12.1	58.5	17.1	82.9
	Mangifera indica	10.4	52.5	16.5	83.5
	Azadirachta indica	10.5	63.5	14.2	85.8
	Aegle marmelos	16.3	64.1	20.3	79.7
	Ficus bengalensis	12.1	62.8	16.2	83.8
	Butea monosperma	8.8	33.5	20.8	79.2
	Eucalyptus	12.2	35.8	25.4	74.6
	Datura alba	1.3	2.1	38.6	61.4
	Nerium indicum	12.9	45.1	22.3	77.7
	Tamarindus indicum	17.1	53.8	24.2	75.8
	Calotropis procera	10.7	72.3	12.9	87.1
	Withania somnifera	17.6	63.9	21.6	78.4
	Acacia arabica	16.1	49.1	24.6	75.4
	Ipomea nil	13.8	51.9	21.1	78.9
	Ficus religiosa	12.9	66.6	16.3	83.7
	Ocimum bacilicum	10.5	60.4	14.8	85.2
	Shorea robusta	10.9	50.4	17.8	82.2
	Cinnamomum L.	16.4	44.9	26.7	73.3
	Garcinia indica	9.4	62.6	13.1	86.9
Crop residues (n = 8)	*Vigna mungo fodder*	10.9	64.1	14.5	85.5
	Vigna mungo husk	29.6	58.7	33.5	66.5
	Oryza sativa fodder	10.8	51.5	17.3	82.7
	Oryza sativa husk	9.8	57.8	14.5	85.5
	Triticum S. fodder	13.9	47.4	22.7	77.3
	Lens E. husk	8.8	60.6	12.7	87.3
	Coriandar C. husk	5.8	65.5	8.1	91.9
	Lin husk	12.3	63.9	16.2	83.8
Incense (n = 10)	Mumtaj	6.2	49.4	11.1	88.9
	Krishna	9.1	64.4	12.4	87.6
	Lubhan	9.0	73.2	10.9	89.1
	Parivar 100	8.8	58.4	13.1	86.9
	Bharat Darshan	4.1	47.5	8.0	92.0
	Silver kobra	11.0	59.7	15.6	84.4
	Singarpuri	4.3	25.2	14.5	85.5
	Dhoop	8.7	45.1	16.2	83.8
	Lobhan powder	2.9	65.7	4.3	95.7
	Camphor	35.5	30.2	54.0	46.0
Mosquito coil (n = 4)	Hit	7.2	36.6	16.4	83.6
	Jet	5.5	30.4	15.3	84.7
	Mortein	5.6	31.1	15.3	84.7
	Tartoise	5.6	35.0	13.7	86.3

Among the all selected materials, the concentration trend for EC was found in the following order: wood □ kerosene □ crop residue □ cow dung □ incense □ coal □ mosquito coil □ LPG; OC was found in the following order: wood □ crop residue □ incense □ cow dung □ coal □ mosquito coil □ kerosene □ LPG; TC was found to be similar trend like OC except the reverse order of mosquito coil and kerosene. The highest concentration of OC was observed in all tested materials except for kerosene and camphor compared to the EC, indicate that OC was the predominant contributor to the total carbon and similarly, total carbon is a significant contributor to the total PM_{10}. The OC concentration was observed lower for LPG, a cleaner fuel than the other fuels. The fuel choice and ventilation factors may also affect the indoor air pollution. It has been reported that open or well-ventilated room lowers the PM concentration and therefore, OC concentration in the cooking and living areas [21]. The indoor burning materials i.e. incense and mosquito coil were also found to be a significant contributor of carbonaceous particulates in indoor environments and seems to be almost equal responsible for indoor hazardous effect like fuels.

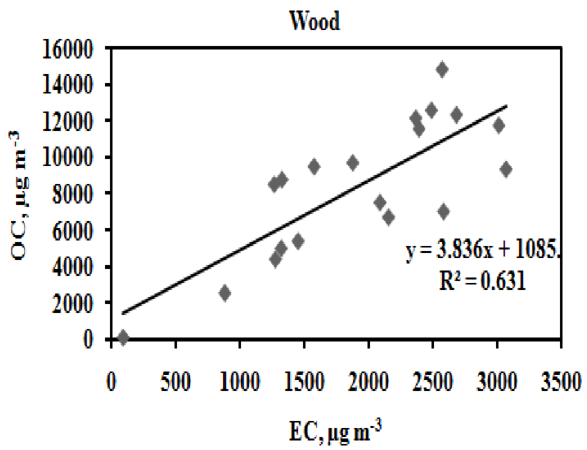
OC/EC CONCENTRATION RATIOS

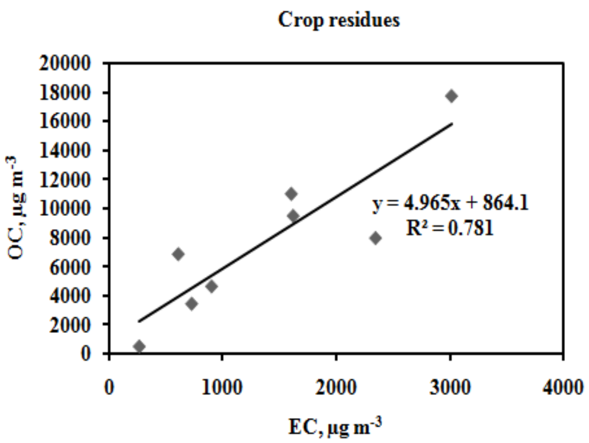
The OC/EC ratios depend upon emission sources and secondary organic carbon (SOC) formation. The mean OC/EC ratios of the LPG, kerosene, coal, cow dung, wood and crop residue smokes was found to be 3.3±1.2, 0.2, 2.9±2.1, 4.2, 4.3±0.6 and 5.7±1.9 respectively, Table 1. The highest OC/EC ratios was observed with cow dung, wood and crop residue and comparatively lower ratios for fossil fuel i.e. LPG, kerosene and coal. The OC/EC ratios of biomass i.e. wood and crop residue was ranged from 1.6-11.3 with mean value of 4.7±0.8. The mean OC/EC ratio of biomass in this study was found almost near with the mean OC/EC ratio reported by Saud et al., [23], (i.e. 5.20) and Saud et al., [24], (i.e. 4.07) for different biomass fuels used in domestic sector of Indo-Gangetic Plain India. Similarly, Venkataraman et al., [25] has reported OC/BC ratios in the range of 0.28-9.09 for biofuels used in India. Saarikoski et al., [26] has reported the mean OC/EC ratio of 6.6 from the burning of biomass fuel in northern European urban air, whereas, Sandradewi et al., [27] has reported OC/EC ratio of the order of 7.3 in the emission from wood burning. It is declared that the higher OC/EC ratio in ambient air of northern India shows influence of biomass burning burning (as well as biogenic sources), while lower ratios to fossil-fuel burning [28].

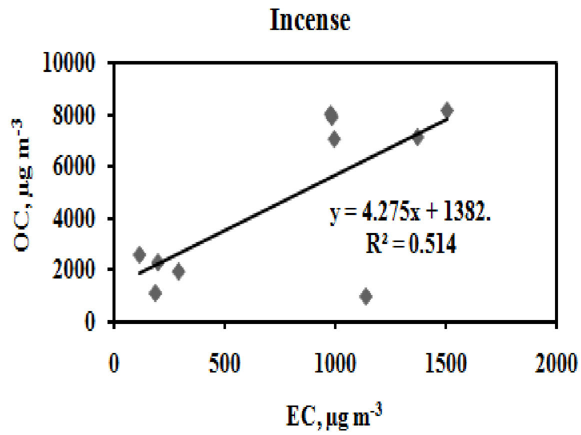
Similarly, the OC/EC ratios of the incense and mosquito coil were ranged from 0.9 – 22.4 and 5.1 – 6.3 with mean value of 8.1±3.5 and 5.6±0.5, respectively, Table 1. The OC/EC ratios incense and mosquito coil varied from sample to sample. Wang et al., [5] has reported OC/EC ratios in $PM_{2.5}$ for three different type of incense ranged from 7.0 to 39.1 with mean value of 21.7 for the traditional incense; from 3.2 to 1.9 with mean value of 7.7 and the highest value was found with church incense. Wang et al., [22] has reported the mean OC/EC ratios ranged from 2.6-17.0 in PM_{10} and from 4.2-18.0 in $PM_{2.5}$. Biomass is a base material of incense and mosquito coil. By comparing, the OC/EC ratios of incense and mosquito coil to biomass observed almost near value of OC/EC ratios to the biomass in present and reported studies, the difference found may be due to addition of ingredients during making of incense and mosquito coil.

THE RELATIONSHIP BETWEEN EC AND OC CONCENTRATIONS

The EC is predominately emitted from burning sources; it has often been used as a tracer of primary OC. The origins of carbonaceous particles can be qualitatively estimated on the basis of the relationship between EC and OC. If EC and OC are emitted by a primary source i.e. burning, the correlation between the EC and OC concentrations should be high because the relative rates of EC and OC emission would be proportional to each other [8]. In this study, we have evaluated the correlation of EC and OC between only for four types of indoor burning materials i.e. wood, crop residues, incense and mosquito coil shown in Fig. 2. No strong correlations were observed between EC and OC concentration during burning of wood (R^2 = 0.63), crop residues (R^2 = 0.78), incense (R^2 = 0.51) and mosquito coil (R^2 = 0.74) materials. This suggests that EC and OC concentration may not be come only from single primary sources but would be impact of other secondary source i.e. SOC. This reason requires further investigation of SOC contribution during burning of indoor materials.







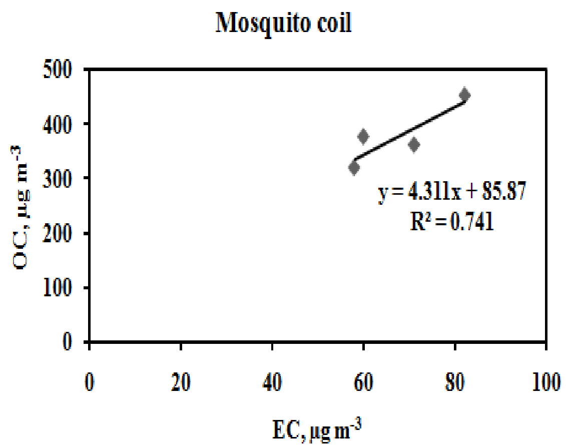


Fig. 2. Correlation of EC and OC concentration during burning of materials i.e. wood, crop residues, incense and mosquito coil.

SECONDARY ORGANIC CARBON (SOC) ESTIMATION

EC is relatively stable in comparison with OC and mainly comes from primary sources. OC can be emitted as primary particles and through secondary atmospheric photochemical reactions. OC/EC ratios close to unity commonly indicates dominance of primary sources since most of EC and OC come from the same source. The ratios of OC/EC larger than 2.0 [13, 30] has been used to identify the presence of SOC. The following equation (2) was used for the quantification of SOC as proposed by Castro et al., [13]:

$$SOC = OC_{total} - EC(OC/EC)_{min} \quad (2)$$

In this equation the minimum OC/EC ratio of the whole dataset of each material was used and that assume carbonaceous particulate matter contribution i s mainly from primary sources andSOC is negligible. This OC/EC minimum ratio was then multiplied by individual EC data to obtain primary organic carbon (POC), and then this value was subtracted from the corresponding total OC to estimate SOC value. In the present work, we have calculated the SOC value only for four types of indoor burning materials i.e. wood, crop residues, incense and mosquito coil. The minimum OC/EC ratios i.e. 1.6, 2.0, 0.9 and 5.1 were used for

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wood, crop residues, incense and mosquito coil materials, respectively. The highest SOC formation was found with wood (5380±1301 µg m^{-3}) followed the order crop residues (4992±2590 µg m^{-3}), incense (4039±1760 µg m^{-3}) and mosquito coil (33±29 µg m^{-3}) which correspond to 58.1%, 56.1%, 79.6% and 8.5% to the total OC, respectively. The three materials i.e. wood, crop residues and incense was found to be greater (more than 50%) contributor of SOC than the POC (i.e. 3072±403 µg m^{-3}, 2749±1072 µg m^{-3} and 661±189 µg m^{-3}, respectively), but in mosquito coil higher POC (345±26 µg m^{-3}) was marked than the SOC value. This may be due to burning condition (i.e. intermediate behavior between low and high temperature) of mosquito coil than the other three materials (i.e. high temperature burning), [31]. It has been found that SOC concentration increases with temperature due to greater formation of radicals in high temperature than in the low temperature [32].

EMISSION FLUXES OF CARBONS

The EC and OC emission fluxes for the solid fuels i.e. coal, cow dung and wood, and incense and mosquito coil are measured. The EC and OC emission fluxes were ranged from 0.17 – 0.77 and 0.85 – 1.83 g kg^{-1} with mean value of 0.38±0.27 and 1.41±0.45 g kg^{-1} for wood (n = 4), respectively. Similarly, the EC and OC emission fluxes were observed to be 0.96 and 2.79 g kg^{-1} for the coal (n = 1), and 1.10 and 4.57 g kg^{-1} for cow dung (n = 1), respectively. The highest EC and OC emission fluxes were marked with the cow dung, may be due to their burning in smoldering fire lead to emission rates of carbons [33]. The EC and OC emission fluxes of fuels i.e. coal, cow dung and wood were found to be comparable with other reported studies. Venkataraman et al., [25] has reported EC and OC emission fluxes ranged from 0.38- 0.62 g kg^{-1} and 0.17-4.69 g kg^{-1} for wood, and 0.12-0.17 g kg^{-1} and 0.25 g kg^{-1} for dung cakes burning in south Asia, respectively. Bond et al., [34] has presented EC and OC emission fluxes ranged from 0.3- 1.4 g kg^{-1} and 1.7-7.8 g kg^{-1} for wood, and 0.53 and 1.8 g kg^{-1} for dung cake, respectively. However, Saud et al., [23] has measured mean EC and OC emission fluxes to be 0.35 and 0.95 for wood, and 0.49 and 3.87 g kg^{-1} for dung cake, respectively. Whereas, Saud et al., [24] has observed mean EC and OC emission fluxes to be 0.37 and 1.07 for wood, and 0.51 and 4.32 g kg^{-1} for dung cake in Indo-Gangetic Plain India, respectively. Zhang et al., [35] has accounted mean EC and OC emission fluxes to be 0.57 and 2.69 g kg^{-1} for wood and 0.01 and 0.31 g kg^{-1} for coal, respectively. Zhang et al., [36] measured mean EC and OC emission fluxes were 0.03 and 0.47 g kg^{-1} for residential coal burning, respectively. Similarly, the EC and OC emission fluxes for the incense fuming were ranged from 0.21 – 0.46 and 1.41 – 6.03 g kg^{-1} with mean value of 0.35±0.10 and 4.15±2.00 g kg^{-1}, respectively. Whereas, the EC and OC emission fluxes for the fuming of mosquito coil were ranged from 1.05 – 2.30 and 5.81 – 9.43 g kg^{-1} with mean value of 1.76±0.51 and 7.92±1.54 g kg^{-1}, respectively. The base material of incense and mosquito coil is biomass. By comparing the EC and OC emission fluxes of incense and mosquito coil with wood, we found several folds higher fluxes of EC and OC with the mosquito coil as compared to the wood (0.38±0.27 and 1.41±0.45 g kg^{-1}), may be due to their fuming in smoldering fire as well as addition of ingredients during making of mosquito coil. Study reported that smoldering fire particles are composed dominantly by organic matter [37]. Stabile et al., [38] has observed EC emission fluxes ranged to be 0.03-0.05 g kg^{-1} for incense and 0.01-0.06 g kg^{-1} for mosquito coil, respectively. Wang et al., [5] has reported mean EC and OC emission fluxes of 0.44 and 7.45 g kg^{-1} for traditional incense and 0.72 and 5.15 g kg^{-1} for aromatic incense in $PM_{2.5}$, respectively. The emission fluxes vary for different incenses and different particle size. The different trend of EC and OC emission fluxes for coal, cow dung, wood, incense and mosquito coil was observed i.e. the EC was found in following order: mosquito coil □ cow dung □ coal □ wood □ incense; and the OC was found in following order: mosquito coil □ cow dung □ incense □ coal □ wood . The mosquito coil was found to be greater emitter of carbonaceous particulates than the other four materials.

IV. CONCLUSION

In this study, indoor emissions of carbonaceous particulate (EC and OC) during burning of materials (i.e. LPG, kerosene, coal, cow dung, wood, crop residues, incense and mosquito coil were investigated in indoor environments, that may be valuable in evaluating future health risk and developing exposure assessment. The highest OC concentration was observed in all tested materials except for kerosene and camphor, shows OC is a predominant contributor to the total carbon. Similarly, the highest total carbon was observed during wood burning, indicates the harmful impact to the women and children who spent more time in indoor environment i.e. kitchen. Whereas, the lowest total carbon was seen for LPG, shows it is a cleaner fuel than the other. The incense and mosquito coil were also marked to be important contributor of carbonaceous particulates and harmful likely to biomass fuels. It was observed that the fuel type and ventilation factor also affect the concentration of carbonaceous particulates in indoor environments. The OC/EC concentration ratios and correlation between EC and OC indicate there is major contribution of SOC during wood, crop residues and incense burning. The different result was observed in the case of mosquito coil, which is a major contributor of POC than the SOC due to their different burning condition. Similarly, the highest emission fluxes were marked for mosquito coil, may be due to their fuming in smoldering fire as well as addition of ingredients during making of mosquito coil. Thus, it is suggested that emission control during indoor burning material is important to indoor air quality and climate change mitigation also.

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