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Estimation of gaseous products and particulate matter emission from garden biomass combustion in a simulation fire test chamber

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Abstract

Air quality in many of the cities in India is gradually deteriorated due to various activities. One of such activities is open burning of garden biomasses in cities. This study was aimed to estimate the emissions from various types of garden biomasses, namely grass, leaves, twigs and mixtures of these three in a controlled SIFT chamber. Though the particulate emission ($1.51\,g\,kg^{-1}$) was the lowest from grass, the particle size distribution indicates that the emission contains 10% of fine particulates ($<2.5\,\mu m$) and significant quantity (70%) of respirable fraction ($<10\,\mu m$). On the other hand, leaves, though generating $32.3\,g\,kg^{-1}$ particulate matter, contained major portion in non-respirable range (around 40%). CO_2 emission from leaves ($1064.6\,g\,kg^{-1}$) and twigs ($897.3\,g\,kg^{-1}$) are significantly lower than the emission from a mixture ($1423\,g\,kg^{-1}$) of equal proportion of these two. Similar trend is followed in case of carbon monoxide and nitrogen oxide emissions. However, hydrocarbon emission followed a reverse trend of emitting high emission load ($11.4\,g\,kg^{-1}$) in the mixture of leaves and twigs than their individual type ($2.4\,g\,kg^{-1}$ (leaves) and $0.2\,g\,kg^{-1}$ (twigs)). The toxicity indices for all categories were very low (0.06–0.12). However, out of the five categories, grass was found to have the lowest toxicity index (0.06) and followed by the mixture (1:1:1), having 0.07. The particulate matter emission load computed for the cities of India shows that the leaves and grass contribute 97 and 4.5 tons day^{-1}, respectively. Among the gaseous pollutants, CO_2 emission was the highest, as the computed values were 3212 tons day^{-1} from leaves and 92 tons day^{-1} from grass.
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Keywords: Garden biomass; Combustion gases; Particulate matter emission

1. Introduction

Air quality in many of the major cities in India is accentuated and gradually leading to the excesses of ambient air safe limits. Delhi, the capital of India, is the most polluted city in the world (WHO, 1992). Suspended particulate matter (SPM) is an extensively used parameter for determining the air quality in India till 1994 and respirable suspended particulate matter (RSPM-PM10) was introduced in 1994 and efforts are on to consider PM2.5 in place of total SPM (Sengupta, 2002). Both coarse and fine particulate matter are of health concern (USEPA, 1997b). Fine particulates are of greatest concern (USEPA, 1997a). The daily mortality is more strongly associated with concentrations of PM2.5

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than with the concentration of large particles (Klemm et al., 2000).

Studies in India and Nepal showed that non-smoking women who have cooked on biomass stoves exhibit a higher prevalence of chronic lung disease, asthma and chronic bronchitis, and a study on western India found a 50% increase in still births in women exposed to indoor smoke during pregnancy (Liousse et al., 1996). Volatile organics and polyaromatic hydrocarbons (PAHs) are sorbed on small inhalable particles and therefore increasing the potential harmful effects on human health (Nicolaou et al., 1984).

On a global basis, the major source of carbonaceous aerosols is due to biomass burning (Sengupta, 2002), and estimated to be 23–27% of measured total aerosol mass concentration (Ramanathan, 2001). The main sources of air pollutants in Indian cities are fossil fuel burning, power stations, vehicular transport, industries, domestic coal and open biomass burning (MoEF, 1997), which are responsible for high value of benzene, toluene, xylene, PAH, sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and heavy metals in the city air (Gautam et al., 1998).

India being an agricultural-dependent country generates a large quantity of agro-wastes. Around 25% of the crop residue generated during each cultivation is burnt in the agricultural fields (Reddy et al., 2002). In India, each city is rapidly expanding and leading to replacement of natural green cover with concrete building, roads, and pockets of open space and parks, which are filled with selective decorative avenue plantations, lawns and gardens. This green cover is periodically pruned, trimmed and loped to enhance aesthetic vistas. This process generates a significant quantity of garden biomass.

Emissions from biomass burning contribute a major part of trace gases and particulates that comprise CO, hydrocarbon (HC), Carbon dioxide (CO_2) and particulate matter with smaller amounts of NO_x and SO_2 and significantly impact the photochemistry of the atmosphere (Crutzen and Carmichael, 1993). Biomass burning also contribute to the ambient concentration of fine (PM2.5) particulate matter (Rogge et al., 1998; Schauer et al., 1996; Centi et al., 1999). Numbers of studies have been carried out to assess the gaseous and particulate matter emission from various biomaterials. Few relevant studies are PAH from fires of wood chips (Bhargava et al., 2002), from cereals and woods (Jenkins et al., 1996a, b), from domestic cooking using sawdust briquettes, wood and kerosene (Nguyen et al., 2002), and fine particle and gaseous emission rates from residential wood combustion (McDonald et al., 2000).

In this study, an effort was made to estimate the emissions from garden biomass burnt in a controlled environmental conditions in a simulation fire test (SIFT) chamber with an intention to highlight the impact of open burning of garden biomass in the environment. The study was aimed to cover (i) particulate emissions and their size fractions, (ii) gaseous products namely CO_2, CO, NO_x and HC, (iii) computing emission factors for various compositions of garden biomass, (iv) estimation of emissions load in the cities of India and (v) assess the toxicity index of these biomasses based on the gaseous products.

2. Experimental

2.1. Simulation fire test chamber

A SIFT chamber was designed and installed in the laboratory. The schematic sketch of the chamber is shown in Fig. 1 along with locations of sampling points. The chamber had a dimension of $4 \times 3 \times 2\,m^3$ size and having 0.2 μm high-efficiency particulate arrester (HEPA) filter bank at the inlet side to arrest particles

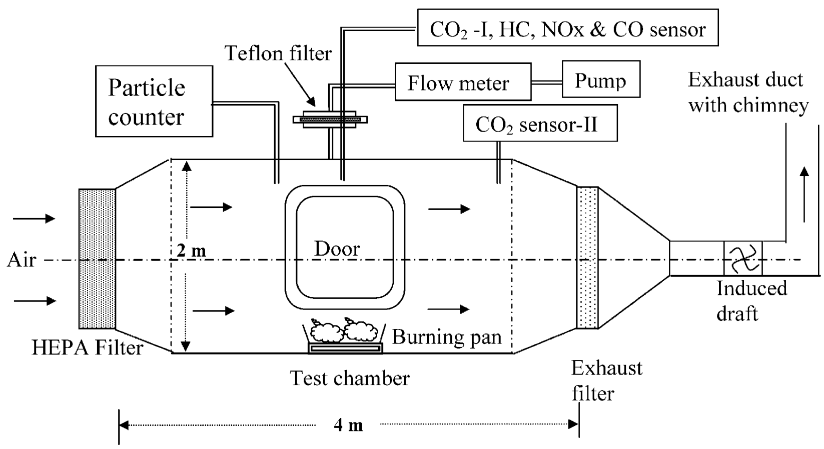

Fig. 1. Schematic diagram of simulation fire test (SIFT) chamber with sampling attachment.

having diameter of more than 0.2 μm from entering the chamber. At the other end, induced draft ($1\,m^3\,s^{-1}$) has been provided to evacuate the chamber before the start of each experiment. Before the ID fan, a pack of pre-filter has been provided. In the centre of the chamber, a pan of an electronic balance (sortorious-genius with an accuracy of 1×10^{-5} g) is provided, where the selected biomass and various composition of biomasses were allowed to completely burn in the chamber and the gaseous emissions were allowed to homogenously mix within the chamber. The combustion is generally completed in 6–10 min and homogenisation of emissions is ensured in the same time with the help of CO_2 sensors mounted in the centre and corner of the chamber. From the roof of the chamber, known quantity of representative particulate and gaseous samples were collected.

2.2. Sources of garden biomass

The main parts of many plants, namely leaf and twigs, were separately collected from mango (*Mangifera inidca*), neem (*Azardica indica*), peepal (*Ficus religiosa*) and ashoka (*Polyalthia longifolia*), which are commonly occurring in parks, and trimmed part of *Sacharum* grass was also collected from the parks and lawns of one of the office complexes of Defence R & D Organisation in Delhi, India. The biomasses were air-dried and the moisture content was determined as per the standard procedures. Different quantities (15, 30 and 60 gm) and composition (leaves and twigs in 1:1 ratio and mixture of leaves, twigs and grass in 1:1:1 ratio) of these garden biomasses were burnt in a SIFT chamber as per the protocol design. The garden wastes were ignited with the help of 2 ml methylated sprit. Emissions from methylated sprit were separately studied and used for computation of actual emission of garden biomasses. In all categories, three sets of experiments were carried out and one set of sample was collected from each experiment.

2.3. Sample collection and instrumentation

2.3.1. Particulate matter

The chamber was completely evacuated before the start-up of the experiment to remove residual aerosol and gases of the previous experiment. After evacuation, the chamber air was tested for particles presence with the help of particle counter based on laser scattering technique (intra-cavity laser scattering technique—Lasair 1001 with the resolution of 0.1 μm) and using CO_2 sensor for the detection of gaseous background level in the chamber. Initially 2 ml of methylated sprit was burnt, which was used to initiate fire of biomasses during various experiments. Subsequently, ignition of all the selected types of garden waste by methylated sprit was carried out. After homogenisation, air samples were drawn at the rate of 10 lpm through a pre-weighed teflon filter paper of 37 mm diameter (Whatmann). After sampling, the filter paper was carefully removed and conditioned before the measurement of particulate loading. The filter papers were used further for particle size distribution analyses.

2.3.2. Combustion gases measurement

Gaseous products such as NO_x, CO, HC and CO_2 were monitored during each combustion cycle. For measurement of these parameters, metal oxide semiconductor-based sensor (model Figaro TGS 813 make Citi technology-Cititech, UK) was used for NO_x (0–100 ppm), CO (0–500 ppm) and HC (0–100 ppm). The response time of these sensors was <1 s and the resolution was 0.1 ppm. For CO_2 measurement, infrared-based sensor was used (Make Guardian plus, Edinburg, UK). The output of these sensors was in 0–20 mA, which was standardised to ppm concentration with calibration gas mixture. The sensors were periodically calibrated to ensure less drift during the monitoring.

2.4. Particle size distribution analysis

A representative quantity of particulate matter collected from the combustion of garden biomass was taken on Mylar paper. The particles were viewed through digital biological optical microscope (Model DMWB 3) with $100\times$ magnification. In this, Mylar paper slides are prepared by transferring the particulate collected on the Teflon filter paper as per the methods described by Katiyar et al. (2002). Motic Image 2000 software, having capability to measure sub-micron particle, was used to measure the particle size. The numbers of particles were counted and a checklist was prepared and computed.

2.5. Toxicity index computation

The tests to determine the concentrations of toxic gases emitted by complete combustion of small specimens of materials and subsequent calculation of toxicity index are based on the procedure outlined by the UK ministry of defence standard NES 713 (Robert, 2000). The procedure involves the complete combustion of small samples in a known volume and subsequent analysis of the toxic gases evolved. The concentration of each of the gases produced when known quantity of material is burnt and the combustion products diffused in a volume of $1\,m^3$ is calculated using the following equation (Defence standard 02-713 (NES 713), 2000):

$$C\phi = C \times 100 \times V/m, \quad (1)$$

where $C\phi$ is the final concentration of gas in ppm, in $1\,m^3$ volume, C is the concentration of gas in the test chamber (ppm), m is the mass of the test sample (g), V is the volume of the test chamber, m^3, 100 is to normalise to 100 g of mass burnt. The toxicity index is determined as follows:

$$\text{Toxicity index} = C_{\phi 1}/C_{f1} + C_{\phi 2}/C_{f2} + \cdots + C_{\phi n}/C_{fn}, \quad (2)$$

where 1,2, …,n represents each of the gases detected, C_f is the concentration of each gas, in ppm, considered fatal to man for a 30 min exposure time. An index of 1 for a given volume will, on an average, bring about death in 30 min.

3. Results and discussion

3.1. Particulate emission

Varying emission of particulate matter was observed in the study for different garden biomasses. The sampling details such as moisture content of the garden biomasses, quantity burned, etc. are given in Table 1. Particulate matter collected on filter paper represented the emission originating from the respective biomasses, as the methylated sprit, which was used to ignite the biomasses, did not generate any particulate matter. Particulate emission rates were computed from collected samples based on the dry weight (Table 2). The particulate emission rate was 32.3 g kg^{-1} for leaves, which is many folds higher than for other types of fuels reported in literatures such as (i) Vietnamese double skinned cylindrical cook stove (Nguyen et al., 1999) emissions of 110.2, 101.5 and 24.7 mg kg^{-1} for wood, coal briquette and coal, respectively, and (ii) fir and pine slashes study in wind tunnel resulted in 5.9 and 3.9 g kg^{-1}, respectively (Jenkins et al., 1996a). The emission factor values were closely matching the values reported for tropical wood fuel burned in small open stoves (Smith, 1987). The particulate emission was relatively much lower from twigs (4256 mg kg^{-1}) followed by grass (1512 mg kg^{-1}). The mixture of leaves and twigs at 1:1 ratio had emission much lower than their individual combustion. This combined combustion has brought down the particulate emissions of individual garden biomasses by 93.3% (leaves) and 50% (twigs). The mixture of grass, leaves and twigs in equal proportion emitted 4349 mg kg^{-1} of particulate matter. Open burning of garden waste is mostly carried out in mixture with varied proportions as per the generation (Reddy et al., 2002). The reduction in the particulate

Table 1
Details of sampling

Biomass burnt for gaseous sample (g)	15, 30, 60
Biomass burnt for particulate sample (g)	100
Air sampling rate	10 lpm
Duration of sampling	5 min
Background aerosol concentration	70 μg m^{-3} (Sengupta, 2002)

Name of garden biomass	Moisture content (%)	Ambient temperature (°C)	Relative humidity (%)	Particles collected (mg)
Grass	11.9	21	30	0.32
Leaves	9.0	27	40	6.74
Twigs	6.9	28	38	0.89
Leaves and twigs (1:1)	11.4	26	42	0.45
Grass, leaves and twigs (1:1:1)	11.2	22	37	0.91

Table 2
Summary of gaseous and particulate emission factor

Name of garden waste	Particulates (g kg^{-1})	CO (g kg^{-1})	HC (g kg^{-1})	NO_x (g kg^{-1})	CO_2 (g kg^{-1})
Grass	1.5	41.7	3.2	2.2	322.4
Leaves	32.3	70.7	2.4	3.0	1064.6
Twigs	4.3	70.9	0.2	4.6	897.3
Leaves and twigs (1:1)	2.2	42.8	11.4	2.8	1403.3
Grass, leaves and twigs (1:1:1)	4.4	57.3	1.8	1.7	456.2

emissions from the mixture was around 65% compared to the combined average emission of the individual types.

Since it is known from earlier studies that majority of PAH (70–90%) are sorbed on fine particulate matter (Nicolaou et al., 1984) and also inhalation of fine particulate matter (PM2.5) from combustion of biomass has been found to cause serious health effect in India (Rogge et al., 1998; Schauer et al., 1996; CPCB report, 2001), size fraction of particulate emissions is an important aspect. The size fraction results of all types of garden biomass in terms of percent occurrence of various size ranges and also the cumulative percentage of particle fraction are given in Figs. 2 and 3 respectively. Although particulate emission rate was the lowest from grass (1512 $mg\,kg^{-1}$), it constituted a high percentage of respirable particulates as seen in Fig. 2 that more than 25% particles are falling at 6 μm size followed by the mixture of garden biomass (1:1:1). As seen in particulate emission rate, fine particulate generation has also come down when garden biomasses are burnt in mixtures. All types of garden biomasses, irrespective of their individual combustion of mixture, they all generate uniform quantity of fine particulates up to 5 μm. This trend changes above 5 μm. The variation of fine particulate generation from various garden biomasses (Fig. 3.) is around 5–20%. For precise interpretation, the percent occurrence of particulates from various garden biomasses considered in this study

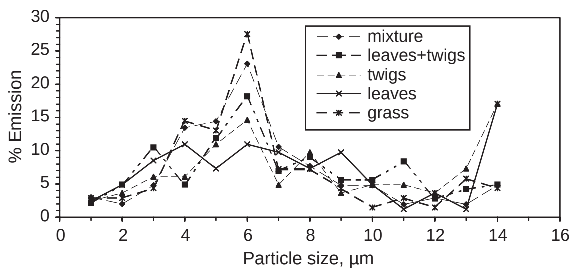

Fig. 2. Percent emission of particulate size distribution during combustion of various types of garden wastes.

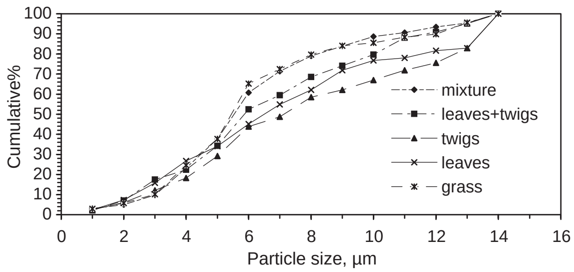

Fig. 3. Cumulative percent emission of particulate size distribution during combustion of various types of garden wastes.

have been grouped into three categories, namely (i) less than 2.5 μm (which has been considered for ambient air quality regulation by USEPA and to be considered by CPCB, India), (ii) 2.5–10 μm, which is currently considered as respirable fraction and ambient air quality standards have been promulgated (Sengupta, 2002) in India and (iii) above 10 μm particulates considered as non-respirable. Accordingly, grass is found to generate more respirable particulate matter, which is around 80% (10% less than 2.5 μm and 70% 2.5–10 μm sizes) followed by the mixture of leaves and twigs (1:1 ratio), generating around 65% (15% less than 2.5 μm and 50% 2.5–10 μm sizes). However, leaves and twigs when individually burnt were found to generate less fine particulates 55–60%. (Fig. 4)

Although the particulate emission (1.51 $g\,kg^{-1}$) was the lowest from grass, the particle size distribution indicates that the emission contains 10% of fine particulates (<2.5 μm) and significant quantity (70%) of respirable fraction (<10 μm) and becomes an environmental concern. On the other hand, leaves, though generating 32.3 $g\,kg^{-1}$ particulate matters, contained major portion in the non-respirable range.

3.2. Gaseous products emission

CO_2 is one of the main greenhouse gases leading to the global warming. Along with natural emissions, human activity leads to the emission of additional amounts of greenhouse gases (Centi et al., 1999). Gaseous emissions of various types of garden biomasses were computed and given in Table 3. CO_2 emission from leaves (1064.6 $g\,kg^{-1}$) and twigs (897.3 $g\,kg^{-1}$) are significantly lower than the emission from the mixture (1423 $g\,kg^{-1}$) of equal proportion of these two. Similar trend is followed in case of CO as well as NO_x emissions. The observed values for CO were 70.7 $g\,kg^{-1}$ (leaves), 70.9 $g\,kg^{-1}$ (twigs) and 42.8 $g\,kg^{-1}$ (mixture 1:1). These values are few folds higher than the reported values for other related biomass combustion such as firewood combustion (25 $g\,kg^{-1}$) (Brocard et al., 1996), fuel wood (9.9 $g\,kg^{-1}$) and agriculture wastes (8.7 $g\,kg^{-1}$) (Hao and Ward, 1993). In the case of NO_x, the values were 3.0 $g\,kg^{-1}$ for leaves, 4.6 $g\,kg^{-1}$ for twigs and 2.8 $g\,kg^{-1}$ for the mixture in equal proportion. These values are found to be many folds higher than the reported values for other types of biomass combustion such as hard wood (0.13 $g\,kg^{-1}$ burned in wood stove) (Mcdonald et al., 2000), agricultural wastes (0.2 $g\,kg^{-1}$) and fuel wood (0.07 $g\,kg^{-1}$) (Hao and Ward, 1993). However, HC emission followed a reverse trend of emitting high emission load (11.4 $g\,kg^{-1}$) in the mixture of leaves and twigs (1:1 proportion) than their individual type (2.4 $g\,kg^{-1}$ (leaves) and 0.2 $g\,kg^{-1}$ (twigs)). The concentration of gaseous emissions from different garden biomass started rising in SIFT chamber only after

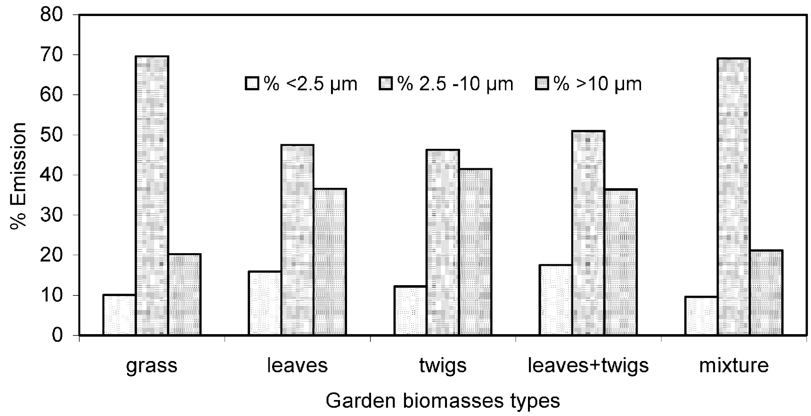

Fig. 4. Percent emission of fine, respirable and non-respirable particulates from combustion of various garden biomass materials.

Table 3
Summary of gaseous emission data

Sl.No	Biomass types	Biomass weight (g)	Concentration ($mg\,m^{-3}$)				Emission factor ($g\,kg^{-1}$)			
			CO	HC	NO_x	CO_2	CO	HC	NO_x	CO_2
1	Grass	15	26.4	2.1	1.3	196.1	42.2	3.3	2.1	313.8
		30	47.1	4.2	2.6	413.1	37.7	3.4	2.1	331.3
		60	113.1	7.7	5.9	805.5	45.3	3.1	2.4	322.2
2	Leaves	15	43.4	1.5	1.9	660.9	69.5	2.4	3.0	1057.4
		30	89.1	3.1	3.8	1330.7	71.3	2.5	3.0	1064.6
		60	178.3	5.9	7.5	2672.3	71.3	2.4	3.0	1068.9
3	Twigs	15	42.7	0.1	3.0	560.4	68.4	0.2	4.8	896.6
		30	91.0	0.3	5.8	1131.7	72.8	0.2	4.7	905.4
		60	178.8	0.6	10.8	2224.7	71.5	0.2	4.3	889.9
4	Leaves and twigs (1:1)	15	28.0	7.2	2.0	868.8	44.7	11.5	3.3	1390.1
		30	50.3	13.7	3.8	1747.9	40.2	11.0	3.0	1398.3
		60	108.6	29.4	5.6	3553.7	43.5	11.8	2.3	1421.5
5	Grass, twigs and leaves (1:1:1)	15	36.3	1.1	1.0	277.0	58.1	1.7	1.6	443.2
		30	68.9	2.3	2.2	573.4	55.1	1.9	1.7	458.7
		60	147.1	4.8	4.6	1166.6	58.8	1.9	1.9	466.6

The values are averages of three sets of experiments.

3 min of ignition and quickly rises to the maximum and then gradually spreads uniformly to the chamber volume. The trend observed for leaves, which is one type of biomasses used in the study, is shown in Fig. 5 and the emission trend of garden biomass mixture (leaves, grass and twigs at1:1:1) is shown in Fig. 6. There is a sharp difference observed in both these experiments. Though the initial trend appears to be the same in both the cases, the concentration rises in CO and HC are quite different. In the case of leaves, the CO rises up to around 50 ppm and subsides to 20 ppm, and remains the same further. However, in the case of the mixture

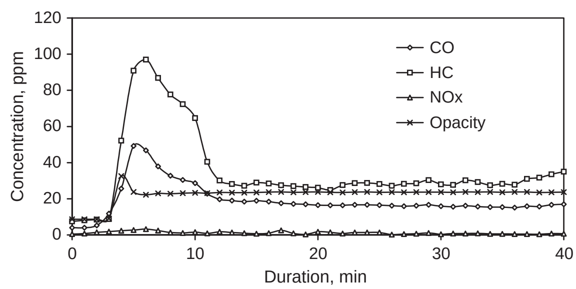

Fig. 5. Concentration of various gaseous emissions during combustion of leaves in SIFT chamber.

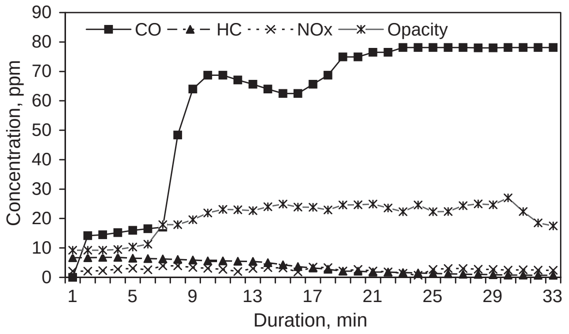

Fig. 6. Trend of gaseous emission from mixture (leaves, grass and twigs)of garden biomass (1:1:1).

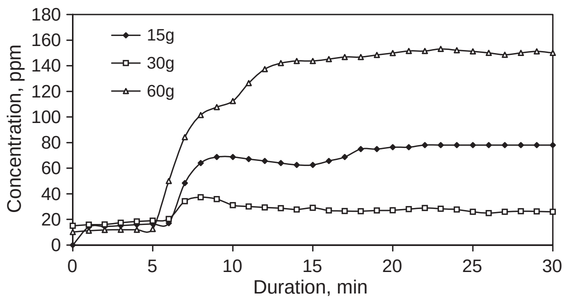

Fig. 7. CO emission from different quantities of mixture of garden biomass (leaves, grass and twigs 1:1:1).

(Fig. 6), CO rises up to 70 ppm and remains the same throughout the sampling period. In the case of HC, again there is a sharp rise (100 ppm) when leaves are burnt and subsides to 30 ppm after 10 min of ignition, and remains at the same level for the remaining duration. On the other hand, when the mixture (1;1:1) was burnt, there was only a minor variation in the concentration (3–5 ppm). The variations of gaseous emission trend have been observed for all the gases by varying the quantity of biomass. One such observation of variation of CO emission from varying quantities of biomass combustion (garden biomass mixtures 1:1:1) is shown in Fig. 7, where after 5 min the CO level started rising and the peak level varied depending upon the quantity of biomass viz 60 g (140 ppm), 30 g (60 ppm), 15 g (25 ppm) burnt.

3.3. Emission loads from biomass generated in cities of India

In India, 30,058 tons day^{-1} of municipal solid wastes (MSW) are generated from as many as 23 major cities, out of which leaves and vegetable comprise 40.15% and grass 3.8% ,and hence 12,070 tons day^{-1} leaves and vegetables, and 1143 tons day^{-1} of grass biomass are generated. Only 5% of total MSW is composted and 94% is dumped in the open area (CPCB report, 2000), and part of this MSW is burnt. The MSW generated from various important cities in India are given in Table 4. Out of the total biomass generated in India, around 25% is burnt in the open area (Reddy et al., 2002). Using the emission factors generated in this study for various gaseous pollutants and particulates, the emission loads per day from each city is estimated. Accordingly, 97 tons day^{-1} of particulate matter from leaves and 4.5 tons day^{-1} from grass are generated from the burnt fraction of these wastes. Among the gaseous pollutants, CO_2 was the highest, as the computed values were 3212 tons day^{-1} (leaves) and 92 tons day^{-1} (grass). Human involvement in this huge emission of greenhouse gases is a point of main concern. The CO_2 emission load is followed by CO as 213 tons day^{-1} from leaves and 11.9 tons day^{-1} from grass were estimated. HC loads from leaves and grass were 7.3 and 0.9 tons day^{-1}, respectively. Similarly, NO_x emissions were 9.1 tons day^{-1} (leaves) and 0.6 tons day^{-1} (grass). Since these emissions are generated by human involvement, this shall be curtailed by adopting alternative disposal mechanisms and effective management measures to reduce the gaseous pollutant emissions.

3.4. Toxicity index

The gaseous product emissions of 15, 30, and 60 g were extrapolated to 100 g of biomass, and toxicity indices were calculated for each quantity of biomass burnt. The computed values along with the average are given in Table 5. Overall, the toxicity indices for all categories were very low (0.06–0.12). However, out of the five categories, grass was found to have the lowest toxicity index (0.06) and followed by the mixture (1:1:1), having 0.07. The indices appeared to be much better in the health exposure point of view compared to the indices of other bio-based materials such as wood packing (1.7), BSD Board (3.7), and other synthetic materials such as PVC electrical wire cladding (1.9), PVC tubing (1.6) and PU foam (1.6) (Kapoor et al., 2004).

4. Conclusions

The study revealed an interesting trend of particulate and gaseous emissions of garden biomasses. Although the particulate emission was the lowest (1.51 g kg^{-1}) from grass, the particle size distribution indicates that the emission contains more fine particulates (10%), and respirable fraction (70%) becomes an environmental concern. On the other hand, leaves, though generating 32.3 g kg^{-1} particulate matters, contained a major portion in the non-respirable range (around 40%).

Table 4
Computed emission loads of gases and particulates of various Indian cities

Name of the Indian cities	MSW generation (tons day^{-1})[a]			Particulates (kg day^{-1})[b]		CO (kg day^{-1})		HC (kg day^{-1})		NO_x (kg day^{-1})		CO_2 (kg day^{-1})	
	Total	Leaves and vegetables[a]	Grass (tons day^{-1})[c]	Leaves & grass	Grass	Leaves	Grass	Leaves	Grass	Leaves	Grass	Leaves	Grass
Ahmadabad	1683	676	64	5462	255	11,945	667	411	52	509	35	179,850	5155
Bangalore	2000	803	76	6491	304	14,195	793	488	62	604	41	213,727	6126
Bhopal	546	219	21	1772	83	3875	216	133	17	165	11	58,345	1672
Bombay	5355	2150	203	17,379	813	38,007	2122	1306	165	1618	110	572,252	16,402
Calcutta	3692	1482	140	11,982	560	26,204	1463	901	114	1116	76	394,537	11,308
Coimbatore	350	141	13	1136	53	2484	139	85	11	106	7	37,401	1,072
Delhi	4000	1606	152	12,981	607	28,390	1585	976	123	1209	83	427,453	12,252
Hyderabad	1566	629	60	5082	238	11,115	621	382	48	473	32	167,345	4796
Indore	350	141	13	1136	53	2484	139	85	11	106	7	37,401	1072
Jaipur	580	233	22	1882	88	4117	230	142	18	175	12	61,981	1777
Kanpur	1200	482	46	3894	182	8517	476	293	37	363	25	128,236	3676
Kochi	347	139	14	1126	53	2463	138	85	11	105	7	37,081	1062
Lucknow	1010	406	38	3278	153	7168	400	246	31	305	21	107,931	3094
Ludhiana	400	161	15	1298	61	2839	159	98	12	121	8	42,745	1225
Madras	3124	1254	119	10,138	474	22,173	1238	762	96	944	64	333,839	9568
Madurai	370	149	14	1201	56	2626	147	90	11	112	8	39,538	1133
Nagpur	443	178	17	1438	67	3144	176	108	14	134	9	47,339	1357
Patna	330	132	13	1071	50	2342	131	81	10	100	7	35,264	1011
Pune	700	282	27	2272	106	4968	277	171	22	212	14	74,804	2144
Surat	900	361	34	2921	137	6388	357	220	28	272	19	96,177	2757
Vadodara	400	161	15	1298	61	2839	159	98	12	121	8	42,745	1225
Varanasi	412	165	16	1337	63	2924	163	101	13	125	9	44,026	1261
Visakhapatnam	300	120	11	974	46	2129	119	73	9	91	6	32,059	919
Total	30,058	12,070	1143	97,549	4563	213,336	11,915	7335	927	9086	619	3,212,076	92,064

[a]Leaves and vegetables composition at 40.15% of total (CPCB report, 2000).
[b]Average combustion of biomass at 25% of generation (Reddy et al., 2002).
[c]Grass composition at 3.8% of total MSW (CPCB report, 2000).

Table 5
Summary of toxicity index of gaseous emission

Sl.No	Biomass types	Biomass weight (g)	Concentration (ppm)			Toxicity index	
			CO	NO_x	CO_2	Individual	Average
1	Grass	15	140.6	4.3	665.6	0.06	0.06
		30	125.7	4.2	701.0	0.06	
		60	150.9	4.8	683.5	0.06	
2	Leaves	15	231.6	6.1	2243.1	0.10	0.11
		30	237.7	6.1	2258.2	0.12	
		60	237.7	6.1	2267.4	0.11	
3	Twigs	15	228.0.	9.8	1902.0	0.12	0.12
		30	242.6	9.5	1920.5	0.12	
		60	238.4	8.8	1887.6	0.11	
4	Leaves and twigs (1:1)	15	149.1	6.6	2948.7	0.09	0.09
		30	134.1	6.1	2966.1	0.09	
		60	144.8	4.6	3015.3	0.08	
5	Grass, twigs and leaves (1:1:1)	15	193.5	3.2	940.1	0.07	0.07
		30	183.6	3.5	973.0	0.07	
		60	196.1	3.8	989.8	0.07	

Leaves and twigs are of medium concern in terms of size fraction compared to grass. Grass constitutes the main garden biomasses contributing to fine particulates as was seen in the mixture (1:1:1) and leaves and twigs (1:1).

CO_2 emission from leaves ($1064\,g\,kg^{-1}$) and twigs ($897\,g\,kg^{-1}$) are significantly lower than the emission from the mixture ($1423\,g\,kg^{-1}$) of equal proportion of these two. Similar trend is followed in case of CO as well as NO_x emissions. However, HC emission followed a reverse trend of emitting high emission load ($11.4\,g\,kg^{-1}$) in the mixture of leaves and twigs (1:1) proportion than their individual type ($2.4\,g\,kg^{-1}$ (leaves) and $0.2\,g\,kg^{-1}$ (twigs)).

Overall, the toxicity indices for all the categories of biomasses were found to be very low. And also, out of the five categories of biomasses, grass was found to have the lowest toxicity index and followed by the mixture (1:1:1). The indices appeared to be much better in the health exposure point of view compared to the indices of other bio-based materials.

The emission load computed for the cities of India shows that $97\,tons\,day^{-1}$ of particulate matter from leaves and $4.5\,tons\,day^{-1}$ from grass are generated from the burnt fraction of these wastes. Among the gaseous pollutants, CO_2 was the highest, as the computed values were $3212\,tons\,day^{-1}$ (leaves) and $92\,tons\,day^{-1}$ (grass). Human involvement in this huge emission of greenhouse gases is a point of main concern. Since these emissions are generated by human involvement, adopting alternative disposal mechanisms and effective management measures to reduce the gaseous and fine particulate pollutants emissions shall curtail this.

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