Asian Journal of Water, Environment and Pollution, Vol. 20, No. 5 (2023), pp. 9-16.
DOI 10.3233/AJW230060

Characterisation of Waste and Assessment of Surface Methane Emissions by Static Chamber Technique at a Major Dumping Site in Central India

Tanmay Srivastava[1,2]*, Smita Dutta[1,2] and M. Suresh Kumar[1,2]
[1]CSIR- National Environmental Engineering Research Institute, Nagpur – 440020, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad – 201002, India
✉ srivastava.tanmay4@gmail.com

Received March 6, 2023; revised and accepted September 3, 2023

Abstract: Given the vast amount and higher organic content of waste generated by developing nations such as India, as well as the challenges related to waste management and global warming, controlling methane emissions from such municipal solid waste (MSW) dumpsites becomes a major concern. As a result, studying the characteristics of solid waste dumped and the subsequent emissions of methane (CH_4) from a site lacking proper disposal and gas emission management facilities, as is common in developing countries, becomes more important for suggesting appropriate corrective measures. In this study, MSW samples were collected from the Bhandewadi dumping site, a prominent site in Nagpur city and subjected to proximate, ultimate, and biochemical analysis. The results showed that the waste had high moisture content due to the tropical climate of the region which, together with the greater carbon content and organic matter (OM), may be responsible for increased overall greenhouse gas emissions. Biochemical study, on the other hand, revealed lower lignin content when compared with cellulose and hemicellulose, which are key contributors to CH_4 emissions. The actual on site measurements using static chamber technique at fresh dumping sites showed that the methane (CH_4) flux was between 1 and 14.3 mg m^{-2} sec^{-2} and 0.9 to 7.11 g m^{-3} day^{-2} at old dumping areas. The study contributes to a better understanding of the amount and unpredictability of methane produced by solid waste in an unmanaged dumping site.

Key words: Municipal solid waste, landfill emissions, methane flux, static chamber technique.

Introduction

Methane is a GHG having 28 times more potency than carbon dioxide (CO_2) when we consider a 100-year time frame according to IPCC AR5. Atmospheric CH_4 concentrations have almost tripled from the pre-industrial period (Dlugokencky, 2021), among which CH_4 emissions from landfills owing to biodegradation of waste is 1-2% (Zhang et al., 2019). According to the World Bank, the worldwide total municipal waste (MSW) generated annually is reported to be 2 billion tonnes. Estimations show the waste generated globally will surpass 3 billion tonnes by the year 2050. Also, it is anticipated that the total generated waste by countries having lower incomes will triple within the same time frame (Kaza et al., 2018). Open dumping is usually carried out in developing and underdeveloped countries on a large scale. Around 31% of the total waste generated is dumped in open dumps (Kaza et al., 2018). The rise in population, inadequate infrastructure in the SWM sector, lack of awareness, insufficiency in resource extraction and limited trained professionals in the waste sector are the major problems and challenges faced by SWM in India (Kumar and Agrawal, 2020).

*Corresponding Author

About half of the total generated waste in India is biodegradable or compostable in nature, and dumping such waste in open sites leads to high GHG emissions (Sharma and Jain, 2020). Also, with the increase in overall population and improving economic conditions in India, the CH_4 emissions have also increased simultaneously. About 3.7% of total GHG emissions in India are contributed by the waste sector. Moreover, an increase in GHG emissions of 2.7 times per tonne of disposed solid waste has also been observed (MoHUA, 2021). In the year 2016, about 60,000 Gg of MSW was disposed off in Indian landfills which resulted in the emission of 754 Gg of CH_4 (MoEFCC, 2021). Several studies have been carried out to measure CH_4 emissions from major dumpsites in India (Table 1).

Problems relating to lack of awareness, habits, rate of development, and varying weather conditions due to different climatic regions are prevalent in India. Due to these challenges and to reduce the impact of CH_4 emissions from the waste sector, it is necessary to generate data on the present emission levels from Indian MSW dumpsites. Owing to the generation of waste containing high organic content, indiscriminate dumping and absence of emission control technologies it is imperative to carry out studies to generate data that may serve as a helpful resource of information for setting up management technologies in the future.

Materials and Methods

Site Selection and Details of the Site

Nagpur is a centrally located city spread over 217 sq.km area (21°08’44”N 79°05’17”E). The population of the city is 2.4 Million and it generates 900 to 1000 tonnes per day (TPD) MSW wherein the biodegradable portion is the highest. After the waste is collected only 15-20% undergoes processing and is treated while the rest is dumped untreated at the dumping site. The waste generated in the city is dumped in the Bhandewadi dumping site which is the only designated disposal site in the city. The site is located at 21°08’24”N 79°09’10”E at an elevation of 320 m, about 8.5 kilometers from the center of Nagpur towards the east of the city. It is spread over an area of 52 acres and operational since 1994. Heaps of waste ranging from 2 to 5 meters can be observed at the dumping yard. There are residential areas within 500 m surrounding the site separated by only a boundary wall. Indiscriminate dumping of waste has led to several problems in the population residing near the site relating to aesthetic issues, groundwater pollution, poor air quality, soil contamination, etc.

Sample Collection and Processing

Samples of the MSW were collected from waste heaps at the Bhandewadi dumping site. A total of 15 samples were randomly collected from waste heaps. The samples were manually segregated to remove items like polythene bags, plastics, pieces of rags and other unwanted refuse. The rest of the material containing organic matter along with certain inert materials, sand, soil, etc. which were difficult to segregate manually, were collected in polypropylene zip lock bags and immediately brought to the laboratory for further analysis. Samples were subjected to moisture content analysis before further processing.

The waste samples were sun-dried for the appropriate time and subjected to grinding and sieving by a 0.45 mm pore size sieve to obtain a uniform sample. Different parameters consisting of pH, OM, proximate analysis (percentage of moisture, ash, volatile matter and fixed

Table 1: Methane emission measurements at various dumpsites in India

City	*Dumpsite*	*CH_4 emissions*	*Reference*
Chennai	Kodungaiyur	1.0 to 23.5 mg m^{-2} h	(Jha et al., 2008)
	Perungudi	0.9 to 433 mg m^{-2} h	
Nagpur	Bhandewadi	0.273 to 1.659 mg m^{-2} s	(Akolkar et al., 2008)
Amravati	Sukali	0.021 to 0.889 mg m^{-2} s	
Chennai	Perungudi	454 mg m^{-2} h^{-1}	(Rawat et al., 2008)
Kolkata	Dapha	405 mg m^{-2} h^{-1}	
Delhi	Okhla	296 mg m^{-2} h^{-1}	
Bangalore	KCDC	194 mg m^{-2} h^{-1}	
Ahmedabad	Pirana	146 mg m^{-2} h^{-1}	
Dehradun	Doran	150 mg m^{-2} h^{-1}	
Guwahati		68 mg m^{-2} min^{-1}	(Gollapalli and Kota, 2018)

carbon) were carried out applying ASTM and ISO standard methnods, ultimate analysis (carbon, hydrogen, nitrogen, sulphur) was carried out using CHNS analyser, heavy metal analysis including As, Cd, Cr, Cu, Ni, Pb, Zn were carried out using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) and biochemical assays like cellulose, hemicellulose and lignin. All the samples were analysed in triplicates for validation of obtained results.

pH and Organic Matter

pH of the waste samples was determined following EPA Method 9045D by preparing a 1:1 suspension. The samples were then tested on the EUTECH ION 2700 Meter.

When biodegradation of OM occurs in the anaerobic environment it leads to emissions of methane and other GHGs. OM was determined (ASTM D2974) by leaving the sample overnight in a muffle furnace at 440°C.

Proximate Analysis

Proximate analysis includes the procedures to determine different components in a sample when it is heated under specific conditions. Parameters such as ash content (AC), fixed carbon (FC), moisture content (MC) and volatile matter (VM) were analyzed. Standard procedures were referred to carry out the analysis.

MC was calculated by drying the sample in the oven at 105°C until the weight of the dried sample stabilised. The calculation to obtain moisture content is as follows:

$$MC\ (\%) = \frac{\text{Wet weight of sample - Dry weight of sample}}{\text{Wet weight of sample}} \times 100$$

AC is the inert and incombustible portion of solid waste leftover after combustion. The waste was ignited at 575°C for 3 hours and the subtraction of the initial and final weight of the sample gives the ash content in percentage (ASTM D3174).

Components other than moisture, given off as gas and vapour during combustion, are termed VM. It was determined by heating the oven-dried sample at 950°C for 7 minutes in a muffle furnace. Afterwards, the sample was immediately cooled in a desiccator, and the weight difference was used to calculate the VM in percent (ASTM D3175).

FC is the remaining solid combustible residue after the dried sample is further heated to remove VM. Hence for obtaining the value of FC following formula is used:

$$FC\ (\%) = 100 - (MC+AC+VM)$$

Ultimate Analysis

Ultimate analysis was carried out to determine the proportions of carbon (C), hydrogen (H), nitrogen (N), and sulphur (S) on a CHNS analyser (Model Vario EL, Elementar Germany).

Heavy Metal Analysis

Heavy metals were analysed by nitric acid digestion of the samples until they became colourless, which were further diluted and analysed on Thermo-Fisher iCAP6300 DUO-ICP-OES.

Biochemical Analysis

The potential of waste to produce methane depends on the composition of substrates present, especially lignocellulose, hemicellulose and cellulose. These were determined by estimation of neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) (Goering and Van, 1975).

Estimation of Stoichiometric Methane and Electricity Potential

The stoichiometric methane potential (SMP) of the waste was determined by the values obtained from CHNS analysis. The following equation was used to calculate the SMP of the collected waste samples (Dutta and Kumar, 2022):

$$C_aH_bO_cN_d + (4a - b - 2c + 3d/4)\ H_2O \rightarrow (4a + b - 2c - 3d/8)\ CH_4 + (4a - b + 2c + 3d/8)CO_2 + dNH_3 \quad (1)$$

$$SMP = 1/8(4a + b - 2c - 3d/12a + b + 16a + 14d)\ Vm$$

Electricity potential was calculated with the calorific value of 1 cubic meter of methane as 36MJ. Considering an electrical conversion efficiency of 35%, 1 m^3 of methane will generate 10 kWh of electricity (Suhartini et al., 2019).

Methane Flux Determination from the Open Dumpsite

Methane gas emitting from the Bhandewadi dumpsite was collected using the static chamber flux technique (Haro et al., 2019) which works to confine the gaseous emissions from the surface of the dumpsite within the static chamber.

Samples were withdrawn at regular intervals (0, 15, 30, 90, and 120 minutes) through septa in the chamber, which is analysed further using gas chromatography. The flux of gas can then be calculated by observing its change over time. Similarly, to determine methane emissions from sites where waste was estimated to be dumped for over 2 years, chambers were left for 24 hrs after which gas samples were withdrawn and analysed.

A PVC chamber having a 24 L volume and 0.51 m^2 area was used to measure the methane flux from the dump site. Fifteen sites, each for new and old waste heaps, were randomly selected throughout the site for placing the chambers which were pressed about 10 cm inside the surface of the site during the duration of sampling. The gas samples were then collected by drawing through a syringe with a stopcock into a sampling vial crimped with rubber septa by the flushing method. The samples were then analysed to determine CH_4 concentrations using the Porapak Q column in Agilent 7890A GC having a thermal conductivity detector.

Results and Discussion

pH and Organic Matter

pH of MSW changes with its stage of degradation ranging between 7 and 8 which falls under alkaline range on the pH scale. The alkalinity or acidity of waste is influenced by the presence of organic acids. The waste samples showed a pH range from 6.8 to 7.35, indicating that it is neutral in nature (Table 2).

OM content in the waste is due to the presence of biodegradable compounds produced primarily from plant and animal sources. The biodegradable matter observed at the Bhandewadi site during sample collection was straws, leaves, twigs and barks of trees, vegetable peels and food waste, waste from slaughterhouses, etc. The chemical compositions of these substrates are the key determinants in the cumulative production of methane. Results from the samples showed a high contribution of OM in MSW composition ranging between 33.37 and 56.23% (Table 2).

Proximate Analysis

MC is the weight of moisture per unit weight of any wet material. MC plays a vital role in microbial activity and hence contributes to methane generation in MSW sites. Although MC depends on factors like climate and composition of MSW, it usually ranges between 15 and 40% and may reach values of 60 to 70% (Ozcan et al., 2016). The MC in samples collected from the Bhandewadi site were subjected to oven drying which gave MC in the range of 35.91 to 49.33% (Table 2). High MC also affects the diffusion of gas through the waste as the pore spaces fill with water and thus may affect the emission of methane and other LFGs from landfills. Ash is the inorganic grey-black amorphous material left behind after the combustion of MSW. Utilisation of ash from MSW includes production of cement, road construction, stabilisation of soil, etc. (Singh et al., 2023). The AC of the waste was found to be in the range of 18.74 to 33.67% (Table 2). Various volatile compounds like sulphur compounds, oxygenated and halogenated compounds along with compounds like terpenes, alkanes and ammonia are emitted from MSW sites (Wu et al., 2020). The collected samples show VM between 23.21 and 32.10% (Table 2). The non-volatile carbon remaining in the sample besides AC and MC after the complete release of VM is the FC. The FC varied from 0.64 to 3.68% in the analysed samples (Table 2). Materials like bones and vegetables are shown to have higher AC and plastics give out maximum VM whereas nutshells and rubber in the waste contribute to higher amounts of fixed carbon content (Zhou et al., 2014).

Ultimate Analysis

The process of organic matter degradation takes place by utilisation of the nutrients available in the substrate (C, H, O and N) by existing microorganisms, which are converted to gases like CH_4 and CO_2. The analysed samples showed high C and O content with C ranging from 19.74 to 32.89% which is also observed in literature with regard to MSW. Percentage of O was obtained by subtraction of C, H, N and S values and AC from 100%.

Heavy Metal Analysis

Leaching of heavy metals occurs when the organic matter in MSW degrades which can show consequences if they reach groundwater. Kitchen waste, ash, paper contribute major concentrations of heavy metals in MSW (Naveen et al., 2018). Heavy metal concentrations in the collected MSW samples were in the following order: Zn>Cu>Cr>Pb>Ni>As>Cd (Table 3).

Biochemical Analysis

Lignocellulosic biomass forms a major part of the organic fraction of MSW. The high cellulose content in waste has been shown to give high bio methane potential (BMP) compared to hemicellulose and lignin (Ma et al., 2019). The percentage of cellulose content dominated between the three with quantity ranging between 21.19 and 33.58%, whereas hemicellulose and lignin content were found to be 6.74 to 13.48% and 9.37 to 15.38%, respectively (Table 2). The cellulose content in biopolymers like paper/cardboard, wood biomass, non-wood biomass and natural fibers falls in the range between 40 and 70%, hemicellulose between 10 and

Table 2: Characterisation of waste dumped at Bhandewadi

		BDW1	*BDW2*	*BDW3*	*BDW4*	*BDW5*	*BDW6*	*BDW7*	*BDW8*	*BDW9*	*BDW10*	*BDW11*	*BDW12*	*BDW13*	*BDW14*	*BDW15*
pH		7.35	7.69	6.8	6.98	6.92	7.31	7.12	7.21	7.1	6.99	7.15	7.14	7.25	6.88	7.2
OM		45.59 ± 0.75	42.14 ± 0.79	50.24 ± 1.14	56.23 ± 0.36	41.57 ± 0.82	33.37 ± 0.84	41.1 ± 0.98	40.06 ± 0.4	54.2 ± 1.04	47.66 ± 0.88	37.94 ± 0.98	47.78 ± 0.67	42.05 ± 0.29	52.35 ± 0.74	49.9 ± 0.54
Proximate Analysis	MC	45.71 ± 0.58	38.37 ± 1.04	48.26 ± 0.08	41.68 ± 0.75	35.91 ± 0.44	40.38 ± 0.18	39.34 ± 0.20	42.76 ± 0.55	49.33 ± 0.59	40.61 ± 0.48	41.93 ± 0.92	39.56 ± 0.07	37.56 ± 0.58	40.99 ± 1.00	44.74 ± 0.53
	AC	24.63 ± 0.82	33.12 ± 0.42	18.74 ± 0.59	30.98 ± 1.39	30.05 ± 0.10	29.43 ± 1.32	33.67 ± 0.71	32.19 ± 0.71	23.25 ± 0.54	33.12 ± 0.21	31.49 ± 1.18	32.35 ± 1.54	29.00 ± 0.17	24.50 ± 0.40	27.52 ± 1.58
	VM	27.61 ± 0.64	24.83 ± 0.85	31.19 ± 0.84	24.35 ± 0.33	31.37 ± 0.11	28.23 ± 0.85	25.95 ± 0.24	23.21 ± 0.33	26.78 ± 0.89	23.98 ± 0.28	23.54 ± 0.47	26.67 ± 0.70	30.99 ± 0.30	32.10 ± 0.19	25.57 ± 0.64
	FC	2.05 ± 0.41	3.68 ± 0.23	1.82 ± 0.17	3.00 ± 0.96	2.67 ± 0.43	1.97 ± 0.64	1.04 ± 0.75	1.84 ± 0.93	0.64 ± 0.24	2.29 ± 0.41	3.04 ± 0.73	1.34 ± 0.77	2.45 ± 0.45	2.42 ± 0.41	2.17 ± 0.40
Ultimate Analysis	C	28.32 ± 0.17	26.06 ± 0.09	30.52 ± 0.31	32.89 ± 0.87	23.75 ± 1.20	19.74 ± 0.34	27.53 ± 0.19	24.85 ± 0.36	32.14 ± 0.20	25.81 ± 0.44	19.94 ± 0.06	31.40 ± 0.15	23.58 ± 0.74	26.41 ± 0.40	23.36 ± 0.65
	H	4.85 ± 0.49	3.55 ± 0.21	6.15 ± 0.07	4.50 ± 0.57	5.10 ± 0.28	4.50 ± 0.42	4.60 ± 0.57	5.50 ± 0.57	6.20 ± 0.14	3.30 ± 0.42	3.70 ± 0.28	4.95 ± 0.35	4.50 ± 0.57	4.35 ± 0.64	4.55 ± 0.92
	N	1.80 ± 0.28	0.90 ± 0	1.70 ± 0.14	0.90 ± 0.14	1 ± 0	0.90 ± 0	0.85 ± 0.07	0.70 ± 0.14	1.30 ± 0.14	0.85 ± 0.21	1.15 ± 0.35	1.35 ± 0.21	0.80 ± 0.14	1 ± 0.28	1.35 ± 0.21
	S	0.45 ± 0.07	0.15 ± 0.07	0.25 ± 0.07	0.10 ± 0	0.05 ± 0.07	0.15 ± 0.07	0.10 ± 0	0.25 ± 0.07	0.20 ± 0.14	0.25 ± 0.07	0.55 ± 0.07	0.15 ± 0.007	0.35 ± 0.07	0.15 ± 0.07	0.30 ± 0.14
	O	39.95 ± 0.51	36.21 ± 0.79	42.65 ± 0.61	30.63 ± 1.55	40.05 ± 1.51	45.28 ± 0.63	33.24 ± 1.16	36.51 ± 1.57	36.91 ± 0.49	36.67 ± 0.09	43.17 ± 1.10	29.80 ± 2.32	41.77 ± 1.40	43.59 ± 1.65	42.92 ± 0.35
Biochemical analysis	CL	28.56 ± 0.42	29.75 ± 0.55	21.82 ± 0.95	26.68 ± 0.36	26.70 ± 0.34	24.88 ± 0.52	26.96 ± 0.12	23.11 ± 0.42	33.58 ± 0.26	25.40 ± 0.71	23.46 ± 0.14	21.49 ± 0.50	30.69 ± 0.88	21.19 ± 0.16	21.62 ± 0.62
	HC	13.48 ± 1.04	9.02 ± 0.47	10.41 ± 0.18	9.94 ± 0.06	10.61 ± 0.27	8.37 ± 0.41	8.67 ± 0.66	8.61 ± 0.13	7.61 ± 0.26	10.49 ± 0.40	11.39 ± 0.66	12.70 ± 0.23	6.74 ± 0.45	9.74 ± 0.51	12.18 ± 0.74
	L	12.11 ± 0.08	10.70 ± 0.54	11.20 ± 0.23	12.59 ± 0.05	11.30 ± 0.61	10.80 ± 0.20	12.17 ± 0.83	13.21 ± 0.00	15.38 ± 0.10	13.67 ± 0.61	13.17 ± 0.02	11.24 ± 0.34	9.37 ± 0.49	10.33 ± 0.16	12.53 ± 0.53

*parameters except pH are in percent (%)

Table 3: Elemental analysis in mg/kg

Sample	*Cd*	*Cr*	*Cu*	*Ni*	*Zn*	*Pb*	*As*
BDW1	0.30±0	107.50±29.56	159.60±15.98	24.15±1.06	249.70±40.59	31.80±2.55	0.70±0
BDW2	0.05±0.07	25.60±6.65	73.80±10.89	14.85±1.48	146.55±7.71	27.65±3.18	1.20±0.14
BDW3	0.65±0.21	44.50±5.37	110.95±20.58	15.50±6.79	173.70±54.87	132.35±67.95	0.10±0.14
BDW4	ND	47.75±22.42	93.20±14.85	22.85±4.03	116.70±50.49	11.85±4.31	0.00±0
BDW5	0.00±0	41.90±2.40	99.50±7.92	24.15±1.20	198.80±5.66	24.45±0.35	0.25±0.21
BDW6	0.20±0.14	58.20±5.37	105.85±25.53	29.10±1.70	135.50±33.38	35.50±9.19	0.45±0.21
BDW7	0.25±0.07	35.45±3.18	93.25±2.33	23.10±3.25	233.05±2.33	34.20±5.09	0.25±0.21
BDW8	0.15±0.07	40.55±1.34	80.50±2.97	23.55±2.90	152.50±10.47	37.05±2.33	0.50±0.28
BDW9	0.20±0	24.05±2.47	97.35±1.48	17.35±2.19	138.25±23.26	79.95±7.71	0.65±0.21
BDW10	0.50±0.14	36.70±3.11	86.55±1.91	22.50±1.41	150.15±34.44	17.80±1.27	1.00±0.14
BDW11	0.35±0.7	26.80±7.07	102.35±0.78	25.70±1.27	140.80±2.97	28.85±1.48	1.35±0.21
BDW12	0.20±0	28.30±4.10	96.20±4.38	14.25±1.34	134.80±9.48	40.25±2.62	1.15±0.21
BDW13	0.50±0.14	45.00±4.95	87.25±2.90	17.85±1.91	192.55±4.03	23.25±2.62	0.60±0.28
BDW14	0.25±0.7	58.95±3.61	80.60±5.52	13.75±1.34	170.35±12.52	30.80±1.98	0.80±0.14
BDW15	0.05±0.7	44.95±5.30	93.90±3.39	22.50±1.41	138.30±6.36	23.95±1.63	1.35±0.21

30% while lignin content was also found to be about 20% (Gerassimidou et al., 2020).

SMP and SEP

Stoichiometry and bio methane potential tests carried out simultaneously show a high correlation. Among kitchen waste which forms a major part of MSW in India, tomato has shown the maximum yield of biogas whereas okra and onion waste show the lowest yields (Prem Ananth and Shanmugam, 2021). It has been shown that SMP agrees with BMP for solid waste. Also, rapid CH_4 generation is observed in wastes having a balanced C:N ratio (Induchoodan et al., 2022). SMP values calculated from the ultimate analysis were between 0.04 and 0.34 L CH_4 g^{-1} VS **(**Figure 1**)**. Cooked food waste has the highest potential for the production of energy whereas textile waste has the lowest (Yasim and Buyong, 2023). SEP calculated from SMP values by considering the electricity potential of $1m^3$ methane to be 10 kWh (Suhartini et al., 2019), showed the average electricity potential of the waste to be 2 kWh per kg VS.

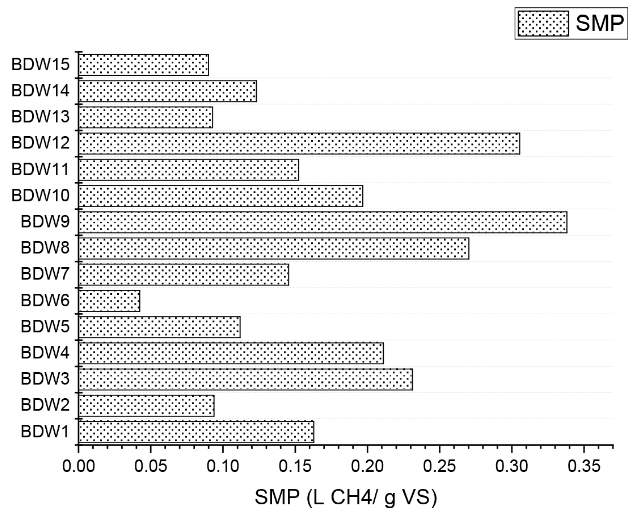

Figure 1: SMP values calculated from the ultimate analysis.

Methane Emission Studies on Bhandewadi Dumping Site

Methane emission studies were carried out on both old and new waste dumped at the site. CH_4 samples were collected from the flux chamber after placing it for 24 hrs at old dump sites, giving values in the range of 0.9

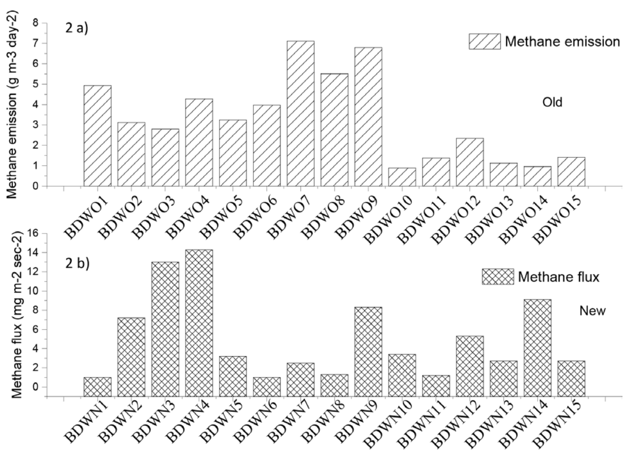

Figure 2: (a) Methane emissions from old waste dumps. (b) Methane flux from new waste dumps.

to 7.11 g m^{-3} day^{-2} (Figure 2a). Also, the flux of CH_4 at new sites was in the range of 1 to 14.3 mg m^{-2} sec^{-2} (Figure 2b). A wide range of emissions was recorded due to the unsegregated nature of waste dumped at the site. Also, municipal waste is collected from various sources which can contribute different amounts of methane emissions into the atmosphere.

Conclusion

This study concludes that the waste dumped in the Bhandewadi dumpsite in Nagpur predominantly comprises organic content with a neutral to slightly alkaline nature. Proximate analysis showed optimal MC for supporting methanogenic activity. Whereas, ultimate analysis led to calculations of SMP and SEP which gave a fair amount of CH_4 emissions 0.04 and 0.34 L CH_4 g^{-1} VS and average SEP of 2 kWh per Kg VS. Cellulose and hemicellulose together constituted a major part in the waste according to biochemical analysis which leads to higher CH_4 production than lignin content which has shown to inhibit the same. The characterisation study reveals the potential of waste to generate higher CH_4 emissions. Data generated from the quantification of on-site CH_4 emission on both old and new waste piles carried out in the current study can assist in the possible use of waste dumping sites for waste-to-energy production with respect to time after considering the feasibility of the process. Also, eco-friendly and economic solutions like the use of microbial methane oxidation by utilizing methanotrophic bacteria through the application of cover systems after closure to reduce the impact of GHG emissions from dumping sites can also be considered to meet the emission reduction goals.

Competing Interests

The authors declare no competing interest.

Author's Contribution

Tanmay Srivastava was involved in sampling, data collection, analysis and writing the original manuscript; Smita Dutta was involved in data collection and performing analysis; Dr. M. Suresh Kumar conceptualised and supervised the entire work.

Acknowledgement and Funding Information

The authors are thankful to Director, CSIR-NEERI for providing necessary resources to carry out this work and Department of Science and Technology, Govt. of India for providing funds in the form of INSPIRE fellowship.

References

Akolkar, A.B., Choudhury, M.K. and P.K. Selvi (2008). Assessment of methane emissions from municipal solid wastes disposal sites. *Res. J. Chem. Environ*., **12(4):** 49-54.

Dlugokencky, E. (2021). Trends in Atmospheric Methane [WWW Document]. [cited 5.16.21]. Available from: http://gml.noaa.gov/ccgg/trends_ch4/. National Oceanic and Atmospheric Administration/GML; 2021.

Dutta, S. and M.S. Kumar (2022). Characterization of floral waste as potential candidates for compost and biofuel production. *Biomass Convers. Biorefinery*. https://doi.org/10.1007/s13399-022-02353-z

Gerassimidou, S., Velis, C.A., Williams, P.T. and D. Komilis (2020). Characterisation and composition identification of waste-derived fuels obtained from municipal solid waste using thermogravimetry: A review. *Waste Manag. Res*., **38:** 942-965. https://doi.org/10.1177/0734242X20941085

Goering, H.K. and P.J. Van (1975). Forage fiber analyses. (Apparatus, Reagents, Procedures and Some Applications) Agriculture Handbook No. 379. ARSUSDA, Washington, DC. U.S. Dep. Agric. pp. 387-598.

Gollapalli, M. and S.H. Kota (2018). Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. *Environ. Pollut*., **234:** 174-180. https://doi.org/10.1016/j.envpol.2017.11.064

Haro, K., Ouarma, I., Nana, B., Bere, A., Tubreoumya, G.C., Kam, S.Z., Laville, P., Loubet, B. and J. Koulidiati (2019). Assessment of CH_4 and CO_2 surface emissions from Polesgo's landfill (Ouagadougou, Burkina Faso) based on static chamber method. *Adv. Clim. Chang. Res*., **10:** 181-191. https://doi.org/10.1016/j.accre.2019.09.002

Induchoodan, T.G., Haq, I. and A.S. Kalamdhad (2022). Factors affecting anaerobic digestion for biogas production: A review. *Adv. Org. Waste Manag. Sustain. Pract. Approaches*, pp.223-233. https://doi.org/10.1016/B978-0-323-85792-5.00020-4

Jha, A.K., Sharma, C., Singh, N., Ramesh, R., Purvaja, R. and P.K. Gupta (2008). Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: A case study of Chennai landfill sites. *Chemosphere*, **71:** 750-758. https://doi.org/10.1016/j.chemosphere.2007.10.024

Kaza, S., Yao, L., Bhada-Tata, P. and F. Van Woerden (2018). What a waste 2.0: A global snapshot of solid waste management to 2050. https://doi.org/10.1596/978-1-4648-1329-0

Kumar, A. and A. Agrawal (2020). Recent trends in solid waste management status, challenges, and potential for the future Indian cities – A review. *Curr. Res.*

Environ. Sustain., **2:** 100011. https://doi.org/10.1016/j.crsust.2020.100011

Ma, S., Wang, H., Li, J., Fu, Y. and W. Zhu (2019). Methane production performances of different compositions in lignocellulosic biomass through anaerobic digestion. *Energy*, **189:** 116190. https://doi.org/10.1016/j.energy.2019.116190

MoEFCC (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.

MoHUA (2021). Circular Economy in Municipal solid and liquid waste. Minist. Hous. Urban Aff. GOI 112.

Naveen, B.P., Sumalatha, J. and R.K. Malik (2018). A study on contamination of ground and surface water bodies by leachate leakage from a landfill in Bangalore, India. *Int. J. Geo-Engineering*, **9:** 27. https://doi.org/10.1186/s40703-018-0095-x

Ozcan, H.K., Guvenc, S.Y., Guvenc, L. and G. Demir (2016). Municipal solid waste characterization according to different income levels: A case study. *Sustainability*, **8:** 1044. https://doi.org/10.3390/su8101044

Prem Ananth, S.C. and P. Shanmugam (2021). Correlation between empirical formulae based stoichiometric and experimental methane potential and calorific energy values for vegetable solid wastes. *Energy Reports*, **7:** 19-31. https://doi.org/10.1016/j.egyr.2020.10.071

Rawat, M., Singh, U.K., Mishra, A.K. and V. Subramanian (2008). Methane emission and heavy metals quantification from selected landfill areas in India. *Environ. Monit. Assess.*, **137:** 67-74. https://doi.org/10.1007/s10661-007-9729-8

Sharma, K.D. and S. Jain (2020). Municipal solid waste generation, composition, and management: the global scenario. *Soc. Responsib. J.*, **16:** 917-948. https://doi.org/10.1108/SRJ-06-2019-0210

Singh, P., Boora, A. and A. Kumar Gupta (2023). A review on utilizing municipal solid waste incineration (MSWIA) in construction activates. *IOP Conf. Ser. Earth Environ. Sci.*, **1110:** 012042. https://doi.org/10.1088/1755-1315/1110/1/012042

Suhartini, S., Lestari, Y.P. and I. Nurika (2019). Estimation of methane and electricity potential from canteen food waste. *IOP Conf. Ser. Earth Environ. Sci.*, **230:** 012075. https://doi.org/10.1088/1755-1315/230/1/012075

Wu, C., Shu, M., Liu, X., Sang, Y., Cai, H., Qu, C. and J. Liu (2020). Characterization of the volatile compounds emitted from municipal solid waste and identification of the key volatile pollutants. *Waste Manag.*, **103:** 314-322. https://doi.org/10.1016/j.wasman.2019.12.043

Yasim, N.S.E.M. and F. Buyong (2023). Comparative of experimental and theoretical biochemical methane potential generated by municipal solid waste. *Environ. Adv.*, **11:** 100345. https://doi.org/10.1016/j.envadv.2023.100345

Zhang, C., Xu, T., Feng, H. and S. Chen (2019). Greenhouse gas emissions from landfills: A review and bibliometric analysis. *Sustainability*, **11:** 1-15. https://doi.org/10.3390/su11082282

Zhou, H., Meng, A., Long, Y., Li, Q. and Y. Zhang, (2014). Classification and comparison of municipal solid waste based on thermochemical characteristics. *J. Air Waste Manag. Assoc.*, **64:** 597-616. https://doi.org/10.1080/10962247.2013.873094