Characterization of combustible fraction of legacy waste: exploring the impact of landfill depth and quantifying energy recovery potential

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Keywords: landfill mining, legacy waste, physico-chemical characteristics, waste-to-energy

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1. Introduction

The amount of legacy waste present in Indian landfills/dumpsites is ~1300 million tonnes and it continues to grow at an alarming rate (CSE, 2020). Most of these sites are open dumps without any provision of cover or lining which causes detrimental impacts on human health and the environment. Landfill mining is one of the potential alternatives to curb those adverse impacts which eliminates the source of contamination. In India, numerous landfill mining projects are underway and tonnes of excavated waste is either stored on-site or disposed in low-lying areas due to lack of knowledge on possible valorization options. Furthermore, the landfills are often managed poorly and lack proper documentation in developing countries such as India, making it difficult to assess the waste composition and estimate the resource recovery potential. The current study aims to assess the composition of legacy waste and the physico-chemical characteristics of combustible fraction for identification of resource recovery options which is necessary for planning of landfill mining activities. Since the landfills are heterogenous and the characteristics of legacy waste can change with depth, influence of depth on waste characteristics was also assessed. In addition to this, energy recovery potential through incineration of combustible fraction of legacy waste was also explored.

2. Materials and methodology

2.1 Waste sampling

Legacy waste samples were collected from a 12 years old municipal solid waste (MSW) landfill in Pimpri Chinchwad, Pune, India. Four sampling locations were selected and the samples were collected up to a depth of 12m. Four samples from each location at a uniform depth interval of 3m were collected resulting a total of sixteen samples. To ensure homogeneity of the samples, coning and quartering method was used and a representative sample of ~15kg was collected from each sampling location. To analyse the moisture content, ~1kg sample from each location was collected in zip lock bags.

2.2 Analytical procedure

The excavated legacy waste was initially dried at a temperature of 85 ºC in a hot air oven for 48 h for determination of moisture content (Quaghebeur et al., 2013). The dry waste was then manually classified into nine different streams namely; fine fraction (<4mm), plastic, stones/construction and demolition (C&D) waste, wood, textile, paper, glass, metal and others. The proximate analysis (volatile matter, ash content and fixed carbon) was done using ASTM standards (ASTM D3174-12, 2018; ASTM D3175-20, 2020). Calorific value and chlorine content of the samples were determined using bomb calorimeter (Advance Research Instruments, Delhi, India) and ion chromatograph (Metrohm IC 732), respectively.

Total energy generation (E) in form of electricity through the incineration of combustible fraction of legacy was calculated using equation (1).

$$E = \frac{CV \times 1000 \times E_f}{3.6} \quad (1)$$

Where, CV is the gross calorific value (MJ/kg) on dry basis, and E_f is the conversion efficiency (assumed as 20%).

3. Results and discussion

The percentage of fine fraction was the highest (32.9%) followed by plastic (28.2%), Stone/C&D (12.6%), wood (10.8%), textile (8.7%), paper (3.4%), glass (1.6%), metal (0.5%), and others (1.3%). High quantity of fine fraction was observed in the zone of 9−12m depth compared to the top layer (0−3m) indicating higher waste degradation in this zone. The overall combustible fraction was ~50% and the top layers (0−3m and 3−6m depth zones) had higher fraction of combustible waste compared to zone of 6−9 m and 9−12 m. Previous landfill exploration studies executed in India showed a higher percentage of fine fraction ranging from 45−75% whereas, the amount of combustible fraction varied from 7−40% (Kurian et al., 2003; Singh and Chandel 2020; Somani et al., 2018). The current study revealed lower amount of fine fraction and high combustible fraction compared to the values reported in the literature. The fine fraction mainly consists of landfill cover soil and degraded organic waste. Since, the waste received at the studied landfill site was segregated into two categories (dry and wet), less organic waste was dumped resulting in a lower amount of fine fraction and higher combustibles.

The average moisture content in the excavated legacy waste was found to be 28.7 ± 13.9% and it showed an increasing trend with depth. The combustible fraction had an average (weighted) volatile matter, ash content, fixed carbon, calorific value and chlorine content of 63.4%, 27.0%, 9.6%, 19.0 MJ/kg, and 0.84%, respectively

(Table 1). The calorific value decreased with increasing depth, whereas no such trend was observed in the other analyzed parameters. As per the solid waste management rules in India, the waste with a calorific value greater than 6.3 MJ/kg would only be suitable for waste-to-energy applications (MoEFCC, 2016). Whereas, according to the guidelines by Central Public Health and Environmental Engineering Organisation (CPHEEO) for utilization of combustible waste as refuse derived fuel (RDF), the minimum calorific value required is 12.6 MJ/kg, with the maximum permissible ash and chlorine content of 15 % and 1% respectively(CPHEEO, 2018). The combustible waste had an average calorific value of 19 MJ/kg, making it suitable for waste-to-energy (WtE) applications, but the high ash content (27%) limits its usage as RDF. The calorific value of combustible fraction on wet basis (29% moisture content), is 13.6 MJ/kg which still satisfies the criteria of RDF. Considering the incineration of dry combustible waste, ~1055 kWh of energy as electricity can be generated from one tonne of waste.

Table 1. Characteristics of combustible fraction of legacy waste from different depths (dry basis)

Waste category	Depth	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Calorific value (MJ/kg)	Chlorine content (%)
Plastic	0-3 m	70.88 ± 0.66	25.81 ± 1.54	3.31 ± 0.88	24.88 ± 2.43	0.14 ± 0.02
	3-6 m	63.97 ± 0.62	31.31 ± 1.58	4.72 ± 2.20	22.83 ± 1.27	0.67 ± 0.05
	6-9 m	74.14 ± 1.38	18.04 ± 0.12	7.82 ± 1.50	22.63 ± 2.28	3.11 ± 0.06
	9-12 m	57.26 ± 4.66	36.72 ± 5.30	6.02 ± 0.63	18.30 ± 0.09	0.32 ± 0.01
Textile	0-3 m	65.41 ± 2.69	24.09 ± 0.33	10.51 ± 2.36	23.35 ± 0.47	0.23 ± 0.02
	3-6 m	71.92 ± 4.35	18.98 ± 3.86	9.10 ± 0.49	20.03 ± 8.33	0.18 ± 0.04
	6-9 m	63.17 ± 10.42	31.68 ± 14.13	5.15 ± 3.71	17.64 ± 4.25	0.78 ± 0.01
	9-12 m	68.57 ± 2.03	18.99 ± 2.07	12.43 ± 0.04	12.62 ± 1.87	0.27 ± 0.02
Wood	0-3 m	56.13 ± 2.10	24.67 ± 0.15	19.20 ± 2.26	13.41 ± 0.08	0.82 ± 0.03
	3-6 m	57.20 ± 4.79	24.37 ± 4.08	18.43 ± 0.71	13.87 ± 0.40	0.52 ± 0.03
	6-9 m	51.86 ± 2.31	26.88 ± 0.66	21.27 ± 1.65	12.80 ± 0.16	0.83 ± 0.02
	9-12 m	53.70 ± 0.37	28.34 ± 0.36	17.97 ± 0.01	11.50 ± 0.01	0.77 ± 0.03
Paper	0-3 m	56.88 ± 1.83	28.60 ± 2.07	14.52 ± 0.25	14.86 ± 0.44	0.53 ± 0.02
	3-6 m	56.55 ± 4.61	30.42 ± 5.55	13.03 ± 0.94	14.26 ± 0.47	0.40 ± 0.02
	6-9 m	58.74 ± 7.82	27.12 ± 3.79	14.14 ± 4.03	13.24 ± 0.12	0.63 ± 0.03
	9-12 m	50.81 ± 0.33	36.37 ± 0.49	12.82 ± 0.17	12.01 ± 0.04	0.78 ± 0.02
Average (weighted)		63.4	27.0	9.6	19.0	0.84

4. Conclusion

No particular trend in the waste characteristics with landfill depth was observed (except for the moisture content and calorific value). High calorific value of combustible fraction confirms its suitability to be used for waste-to-energy applications. However, in order to use the combustible waste as RDF, the ash content may be required to be reduced, which can be accomplished by using appropriate pre-treatment (such as shredding) for removal of adhered impurities.

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