Quantitative determination of energy potential of refuse derived fuel from the waste recovered from Indian landfill

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Abstract

Landfills are urban stocks and resource reservoirs for potential energy recovery. The purpose of this study is to evaluate the amount of energy that could be recovered from aged waste (around 5 - 20 years old) recovered from landfills. Investigations were conducted on the physical and chemical properties of refuse-derived fuel (RDF) prepared from recovered landfill waste (RLW) in Andhra Pradesh, India. Waste characterization studies included determination of waste composition, proximity analysis, ultimate analysis, and energy content. The moisture content ranged between 25.70 to 31.30%, however, no trend was observed with age. In the ultimate analysis, the percentage of carbon increased from 42.94% to 71. 66% with the age of the samples, this is due to an increase in the plastic content over time. The calorific value of the recovered landfill waste ranged from 10.35 MJ/kg to 21.83 MJ/kg. From the findings, it can be summarized that the RDF can potentially be utilized as a feedstock for the recovery of energy from RLW. The results from this study will assist policy makers and local authorities in designing and developing strategies for resource and energy recovery from landfills in different urban cites across the globe.

Keywords: Landfill recovered waste; Refuse derived fuel; Energy recovery; Incineration; Municipal solid waste; Calorific value; Plastic waste

1. Introduction

The amount of solid waste generated globally is expected to increase from 2.01 billion tons in 2016 to 3.40 billion tons by 2050 [1]. Population growth, rapid urbanization, demographic transfers, living habits, industrial, and economic developments are contributing factors to the increase in waste generation trends [2]. The handling, processing, treatment, and disposal of waste plays a vital role in development of good solid waste management systems [3]. In developing countries, it is estimated that municipal governments spend 20-50% of their annual budget on solid waste handling and management [1]. The cost benefit matrix in terms of resource recovery from solid waste is currently negative. It is also estimated that 80-90% of waste in BRICS countries ends up in unlined landfill [4].

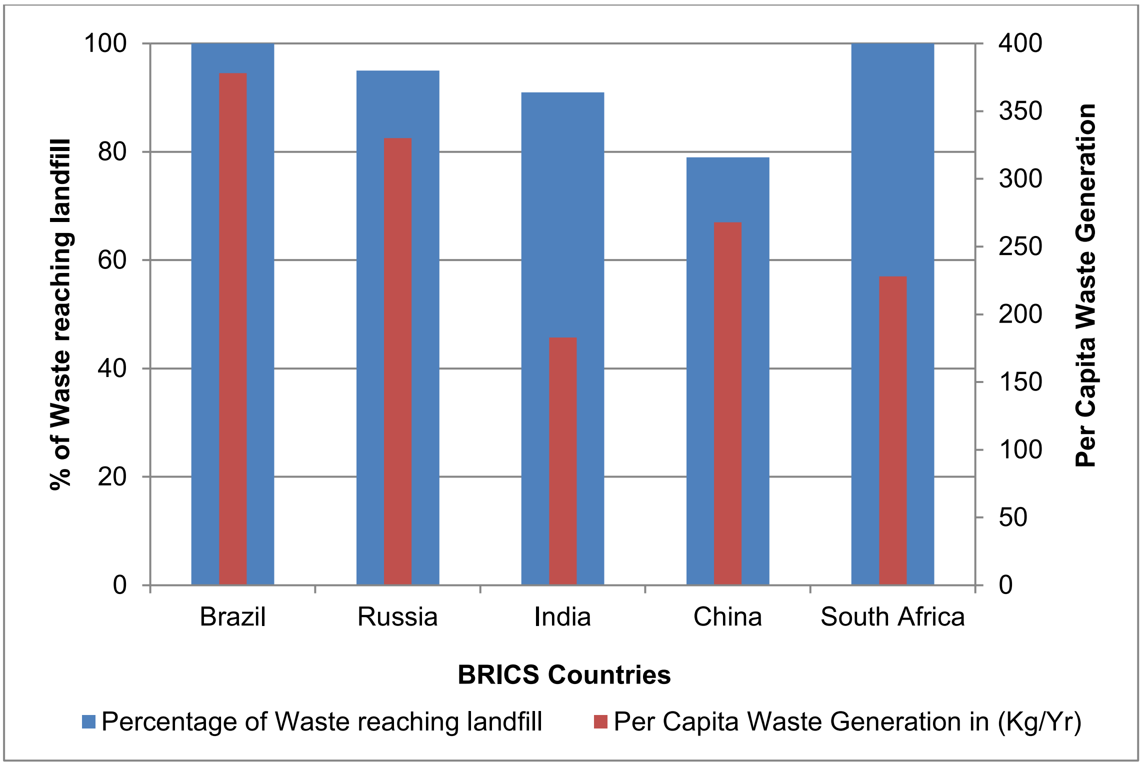

Figure 1 Waste generation and disposal rates in BRICS countries

In Figure 1 shows the waste generation and disposal rates in BRICS countries. The per capita generation rate is highest in Brazil with 378 kg/Cap/Year and the lowest is in India with 183 kg/Cap/Year. In Brazil and South Africa, 100% of the waste collected is dumped landfill. In India 91%, Russia 95% and China 79% of waste is disposed in a landfill [4].

Disposal of municipal solid waste via unlined landfills is a common practice in low income and low-middle income countries. In unlined landfills waste is disposed in an unregulated approach leading to environmental and health hazards. In China, approximately 3 billion ton of municipal solid waste (MSW) is disposed of to landfills over the last 30 years. The Chinese national twelfth five-year plan of MSW treatment and management indicated a budget of 3.4 billion US Dollar for landfill eco-remediation projects in China from 2011 to 2015 [5]. In Germany, about 2.5 billion ton of MSW have been disposed of to landfills since 1975. It is estimated that 250 million tons of combustible material, 26 million tons of iron, 0.85-1.2 million tons of copper and 0.5 million tons aluminum can be recovered from these landfills [6]. The waste dumped in the landfills should be considered as an urban stock and resource reservoir for future resource recovery [7]. In India, 62 million tons of waste is generated in the year 2016, 70% of waste generated is collected of which 22-28% is treated and the rest disposed of in landfills. With the present rate of dumping an area of about 1240 hectares is required to dispose of waste in India alone [8,9].

The development of new landfill poses a critical challenge for local authorities (municipal councils) and regulatory bodies given to economic constraints, environmental policies, and opposition from the community and scarcity of land resources. Councils are encouraged to plan and develop systems like source segregation, recycling, and energy recovery to reduce the environmental burden and increase the lifespan of landfill. An important challenge and critical job for councils is also the aftercare management of the closed landfill [10-15]. Characteristics and composition of landfill waste, geological and geo-technical properties, topography, climatic conditions and ground water flow conditions play a major role in the development of a management plan for landfill aftercare management. The lack of detailed records and databases pose a critical challenge in development of the management plan for leachate, odor, heavy metals, and methane control systems in developing countries [16].

Policies and environmental laws are being developed to create a methodology to extract resources and energy from the existing landfills [17,18]. In India, consumption of energy has increased by 129% between 2000 and 2016. The forecasted annual growth rate of energy for India based on single-linear model to be 4.49%-5.21% from 2017 to 2026 [19]. The energy mix of India is comprised of coal (69%), hydro-power (14%), natural gas (10%), oil (4%), nuclear (2%), and renewable (1%). Energy demand is expected to double by 2035, posing a critical challenge on the sources, generation and supply of additional energy [20]. Global electricity production in 2016, increased by 2.9% reaching 25,082 TWh. Combustible fuels accounted for 67.4% of the total electricity production mix with 65.1% from fossil fuels and 2.3% from biofuels and waste. The remaining 32.6% came from hydroelectric plants (16.6%), nuclear power plants (10.4%), wind, tide, solar and other sources (5.6%). China (24.8%) and United States (17.2%) together account for 40% of total global electricity production. India (5.9%), Russian Federation (4.4%), Japan (4.2%), Canada (2.7%), Germany (2.6%), Brazil (2.3%), Korea (2.2%) and France (2.2%) including China and USA account for two-thirds of the global electricity generation [21]. In USA, electric power (37.1 %), transportation (28.1%), industry (21.9%), residential and commercial uses (10.4%) are the major electricity consumption sectors [22].

A waste hierarchy was developed in India for efficient utilization of resources and to evaluate waste management systems to achieve the objectives of Waste Avoidance and Resource Recovery Act 2001. The waste hierarchy focuses on reducing the waste reaching landfill through the application of the 3R's (reduce, reuse and recycle), source segregation, and technical treatment of waste. Indian solid waste management (SWM) regulations (2016) emphasize investigating the bio-mining and bio-remediation potential of old landfills [23-25].

In landfill mining the old waste is excavated from the landfill sites for resource and energy recovery. Urban land reclamation, extraction of recyclables and waste derived fuels can be achieved through this process [25].

Landfill reclamation and mining research is being carried out globally to understand the technology, economic, and social constraints. Conceptual discussions, feasibility studies and pilot scale investigations are being performed to further understand the process of landfill mining for specified deposits. Composition and characterization analysis are performed on the excavated waste samples based on age and location and are assessed to determine the energy and material recovery potential [26-32]. The waste composition in municipal solid waste landfill typically consists of 50-60% of soil type material, 20-30% combustible components, 10% inorganic components, and a small amount of metals. The variation in the waste compositions from different landfill sites indicates that site specific investigations should be performed to quantitatively determine the material and energy recovery potential [7, 32]. The objective of this study is to determine the physico-chemical characteristics of the different aged-waste samples recovered from the landfill. Investigate the energy potential for RDF prepared from the combustible component to be utilized as a feed stock in thermal based waste to energy technologies.

2. Study Area

The Kapullupada landfill, covering an area of about 38.5 hectares is located 22 km away from Visakhapatnam city in Andhra Pradesh state, India. The landfill is an unlined facility receiving 1250 tons of solid waste on average per day. The dump site is in a small valley, surrounded by hills on three sides and a housing estate on the other. The dump site is 0.5 km away from a national highway (NH-16) and it is within 5 km radius of a coastal zone (Bay of Bengal). Waste has been dumped at this unlined landfill site for the past 20 years.

The average depth of the waste heap from the top of the waste varies from 10 to 12 meters in the sample collection area. Figure 2 represents the sampling locations in the landfill.

Figure 2 Sampling locations in the landfill, Visakhapatnam city

2.1. Sample collection

The sample collection methodology was determined in accordance with ASTM D6009-12 (Sampling Waste Piles) [33] and the number of samples was determined as per ASTM D5321-92 (Reapproved in 2016) [34]. The location for the sample collection was determined through personal interview with the working staff. The samples were collected based on the age of the waste from the sample locations. Figure 2 represents the satellite imagery of the landfill and sample collection area. The age of the waste sample in location 1, varies between 10 to 15 years (S1). The age of the waste sample in location 2 varies between 5-10 years (S2) and location 1 is less than five years (S3). A trenching method was followed to collect the samples from the different depths. Trenches were dug using a bulldozer with a backhoe loader. Initially the top layer containing soil and plants were removed to a depth of 20 cm. The samples collected are well mixed to prepare a representative sample for each sampling location to determine the physico-chemical properties and energy potential. This process of sampling replicates the field practices being followed by a collaborating firm associated with Greater Visakhapatnam Municipal Corporation (GVMC) in the development of a waste-to-energy plant proposal. The sampling was performed from 25th June 2017 to 5th July 2017. The samples were mixed to develop a representative sample.

2.2. Refuse derived fuel sample preparation

The samples collected were initially sieved through the ASTM No. 40 screen to segregate the inert material. The samples were then placed in a hot air oven for a period of 24-48 hours to determine the moisture content in accordance with ASTM E1756-08 [35]. Dried samples were then sieved in a mechanical sieve shaker for 15 minutes and hand sorted to segregate the sample waste into different components. The components are inert material (soil and stones), combustibles (plastics and rags), inorganic (ceramics and glass, metal), and others (wood, coconut residues and bones). The weight of each component was then determined and a pie chart for physical composition of waste samples was developed.

The representative RDF samples (S1) and (S2) were prepared from the combustible component representing 10-15-year-old samples and 05-10-year-old samples. An RDF sample (S3) representing 0-5-year aged sample was prepared by mixing combustible components (plastic and rags), paper, wood and coconut residues. The samples were shredded to achieve a size of 1.0 ± 0.5 cm to perform the experimental studies. All the experiments were performed in triplicates for each sample and the average results were reported.

2.3. Analysis methods

Proximity analysis was performed to determine the volatile solids, fixed solids and ash content. The volatile combustible matter was determined in accordance with ASTM E872-82 (2013) [36]. Silica crucibles containing the samples were covered with lids and they were placed in a thermostatically controlled muffle furnace at a temperature of 550 ± 20°C for a period of 120 minutes to determine the quantity of volatile solids. The ash content was determined in accordance with ASTM D1102-84 (2013) [37]. Silica crucibles without lids were placed in the muffle furnace at a temperature of 550 ± 20°C for a period of 30 minutes. For the elemental analysis, the samples were shredded to a size less than 600 microns. The shredded samples were dried in a hot air oven at a temperature of 103 ± 2°C for a period of 24 hours to remove the moisture content. The elemental composition of the sample was determined using a Euro Vector A3000 elemental analyzer. The calorific value of the samples was determined in accordance with ASTM E711-87 [38]. Pellets of weight 1.0 ± 0.5 gm were prepared from the RDF samples using a hand pelletizer. The pellets were then placed in an adiabatic bomb calorimeter. The initial temperature and the final temperature were recorded for the determination the energy content.

3. Results and Discussions

3.1. Moisture Content

Moisture content for the three samples ranged between 25 to 31% and is represented in the Table 1. Moisture content was high in sample S1 (30.92 ± 0.58) and lowest in the sample S3 (26.43± 0.65). It was observed that moisture content increased with age and depth of the samples. The sample collection was conducted during the pre-monsoon season. The weather conditions were humid and hot with an average temperature ranging between 35 to 40ºC. Initial showers occurred for a short duration. The moisture content value is associated with amount of precipitation, percolation of water in waste piles, water holding capacity, and degradation activity of the organic waste [7]. A two-way ANOVA test indicated that there is no significant difference ($P > 0.05$) in the moisture content obtained from the different age and depth samples.

For incineration, moisture content of the feedstock should be less than 45% [39]. In India, the average moisture content was ranging from 31% to 65%. The percentage varies due the composition, seasonal variations, and climatic conditions. During the incineration plant design for mixed waste, secondary pit has to be designed to drain leachate under gravity. The leachate has to be collected and treated for disposal or application on land. Comingling of wastes with different moisture content is an alternative approach for reducing moisture in waste. For the aged waste, the combustible components (plastic and rags) are contaminated with soil-type material. Pre-heating followed by cleaning systems should be designed remove moisture content and soil-type material. The percentage of moisture content is one of the critical parameters in the design of drying unit.

Table 1 Moisture content analysis of the aged waste recovered from dump sites

Parameter	**Unit**	**S1**	**S2**	**S3**
Moisture Content	% weight	30.92 ± (0.58)	28.67 ± (0.79)	26.43± (0.65)

Value in parenthesis represent *standard deviation*

3.2. Physical composition of the waste

The mean percentage of waste composition (by dry weight) for the samples collected from the unlined landfill located in GVMC is represented in Table 2. It was observed that the soil trends increase with the age of the sample. Drain silt and street sweeping waste are mixed with the waste leading to an increase in soil waste levels. High amount of ash is observed as the rag pickers at the dumping site burn the heaps of waste to recover metal and ferrous material. The plastic waste component of the waste also increases with the age of the waste. It was probably due to increase in the usage of the plastic products after 2000 [40]. The per capita plastic product consumption in India is estimated as 11 kg/person [41]. Plastic is one of the major components that can be harvested from a landfill. The plastic component mainly includes covers, wrappers and 3D films. Water bottles and recoverable plastics are being picked up by the rag pickers for recycling.

Glass, metal and ceramics are being collected by the rag pickers. The organic waste, paper, yard waste and other biodegradable wastes decompose under anaerobic conditions leading to the release of methane gas. In the aged samples 95% of the biodegradable component is decomposed. Table 2 also presents a comparative study on physical classification of the aged waste recovered from dump sites. Two-way ANOVA showed a significant difference ($P<0.05$) in soil-type material, plastics and rags among all waste samples. No significant difference ($P>0.05$) between S1 and S2 was observed for glass, metal, and ceramics.

Composition of landfill waste varies based on geographic location, socio-economic conditions, dietary habits, seasonal variations, recycling rates, and informal sector activity. Designing a system based on the average composition values will reduce the efficiency of the plant. Physical composition of the landfill waste plays a pivotal role in designing a incineration unit to meet the needs of local conditions.

Table 2 Physical classification of the aged waste recovered from dump sites

Location	Visakhapatnam, India			Thailand [31]				Belgium [42]	Thailand [32]
Age in years (→)	10-15 (S1)	5-10 (S2)	< 5 (S3)	2	5	7	10	14-29	3-5
Soil-like material	56.59	53.72	45.93	32.9	56.59	27.86	49.1	44(12)	34
Paper	-	-	2.33	4.09	-	-	-	7.5(6)	3.3
Plastics	23.08	18.62	16.86	36.75	24.64	44.83	35.34	17(10)	31
Rags	2.75	5.84	10.47	11.51	7.45	10.21	1.80	6.8 (6)	7.6
Glass	4.40	4.26	3.49	1.79	4.03	1.21	4.79	1.3 (0.8)	6.5
Ceramics	4.93	4.79	2.33	1.19	0.83	0.73	2.99	-	-
Metal	4.95	4.26	2.91	1.79	1.66	3.34	4.19	2.8(1)	6.4
Others	3.30	8.51	15.70	10.01	4.80	11.83	1.80	16.7	11.3

"-" Not Detected

3.3. Proximate and ultimate analysis

The proximate analysis results of the RDF samples are presented in Table 3. RDF sample (S1) had high volatile solids of 58.75 ± (1.25) % dry weight and low ash content of 11.58 ± (0.31) % dry weight and fixed carbon content of 3.24 ± (0.65) % dry weight as compared to other RDF samples. In the RDF samples the volatile matter ranged between 43% and 58%on a dry weight basis. The decrease in volatile matter from RDF Sample S1 to S3 suggest that the organic matter decreases with the age of the waste. Central Pollution Control Board (CPCB) compiled a report on selection criteria for waste processing technologies [39]. For incineration, the volatile matter should be greater than 45%. In RDF samples S1 and S2 the volatile matter is higher than 45% while in S3 sample the volatile matter is 2.5 to 4.0 % less compared to the desired value. The ash content of the RDF samples ranged between 11 and 18 % on a dry weight basis. The permissible range of ash content to achieve high efficiencies in mass burn incinerators recommended by US EPA is 5-15% (dry basis). In RDF samples S1 and S2 the ash content is within the range while in S3 sample the ash content is 13-18% higher that maximum permissible value. The fixed carbon ranged between 3 and 9 % on a dry weight basis. The high percentage of fixed carbon indicates longer retention times for combustion in incinerator [43].

The volatile solids content of normal plastic (not landfill recovered) is 98.5%, the ash content is 1.2% and the fixed carbon less than 0.1% [7]. In the present study, the representative samples of RDF were prepared without pretreatment for landfill mined plastic and textile components. The impurities attached to the surface are not completely removed. The inert material and impurities from the landfill recovered waste components can be reduced trough a suitable pre-cleaning method during the RDF sample preparation. This will increase the volatile solids, heating value and reduces the ash content of the RDF. Table 3 presents the results obtained and comparative analysis of proximate analysis. The results obtained in the present study are within the range obtained from other similar research. [7, 43].

Table 3 Proximate analysis of the aged waste recovered from dump sites

Parameter	Unit	Present study			*India [43]*	*China [7]*
		S1 (n=9)	**S2 (n=9)**	**S3 (n=9)**		
Volatile Solids	%	58.75 ± (1.25)	51.72± (0.77)	43.67± (0.32)	45.28	87.09 ± 1.09
Ash	%	11.58 ± (0.31)	13.72± (0.15)	17.37± (0.39)	24.71	10.39 ± 0.26
Fixed Solids	%	3.24 ± (0.65)	5.89± (0.79)	8.03± (0.58)	4.53	2.10 ± 0.40

The ultimate analysis results of the RDF samples are presented in Table 4. RDF sample (S1) has a high percentage of carbon 71.66 ± (13.74) dry weight as compared to other RDF samples due to the amount of plastic content. No trend was observed for the plastic waste with age of the samples. The amount of plastic content in the waste depends on the consumption rates, disposal practices and recycling systems in the urban cities. Site specific characterization studies provide in depth understanding on the plastic waste component across the globe.

In RDF samples S2 and S3 the percentage of sulphur was 24.56 ± (3.04) and 32.98± (10.47) on a dry weight basis. The high amount of sulphur is attributed to the formation of oxides of sulphur, hydrogen sulphide and VMOC's with the aerobic and anaerobic decomposition of the waste. The percentage of oxygen in all the samples ranged from 9 to 12%. The percentage of hydrogen and nitrogen was low. The percentage of hydrogen decreased with the age of the waste and no trend was observed in terms of nitrogen and oxygen content.

Table 4 Ultimate analysis of the aged waste recovered from dump sites

Parameter	**Unit**	**S1 (n=5)**	**S2 (n=5)**	**S3 (n=5)**
Carbon	%	71.66 ± (13.74)	57.53± (16.80)	42.94 ± (9.57)
Hydrogen	%	0.87 ± (1.95)	1.54± (2.86)	2.35 ± (2.16)
Nitrogen	%	0.82± (1.12)	0.23 ± (0.29)	1.01 ± (0.69)
Sulfur	%	1.41 ± (0.77)	24.56 ± (3.04)	32.98± (10.47)
Oxygen	%	9.433	9.049	11.480

Value in parenthesis represent standard deviation

3.4. Calorific Value

The calorific value results of the RDF samples are presented in the Table 4. The High Heating Value (HHV) on a dry basis was found to be the highest for the RDF sample (S1) was 20.47± (2.87) MJ/kg and lowest for the RDF sample (S3) was 11.09 ± (0.71). The variations were due to the physical composition of the samples. Using Dulong's equation and elemental composition, HHV (theoretical) was determined for the RDF samples. The HHV (experimental) and HHV (theoretical) for the RDF sample (S3) were found to be matching. However, for the other two RDF samples a percentage variation of 5-15% was observed. As per SWM rules 2016, RDF samples prepared from solid waste are recommended to be utilized as fuel in incineration units, if the calorific value is greater than 1500 Kcal/kg. In the present study, the calorific value of all the three RDF samples prepared from the waste recovered from landfills can be used as a feedstock in mass burn incineration plant. Table 5 presents the results obtained and comparative analysis of energy content. The results obtained in the present study are within the range obtained from similar research [7,39]. The calorific value of landfill recovered waste depends on the composition of the waste and percentage of impurities. In the present study, segregation of the waste in laboratory contributed to achieve high calorific value. However, pre-cleaning was not performed to simulate current field practices. The average calorific value of the plastic material is 43.55 MJ/kg [7]. The calorific values obtained in this study are low compared to the normal plastics. Segregation and pre-cleaning of recovered waste will increase the calorific value of the RDF. Development of pre-treatment systems involves high capital and operation costs and require skilled personal for operation and maintenance [44].

The recovered landfill waste can be utilized to develop RDF or directly incinerated to harness thermal energy using the advancements in current technologies. RDF can mix with sawdust, rice husk, plastic waste, and other combustible components in certain ratio to increase the calorific value of feedstock. According to previous researchers, thermal treatment options are economical compared to chemical recycling methods [7]. Life cycle assessment studies should be conducted on designed treatment systems to develop environmentally sound solution [45-46].

Table 5 Energy content analysis of the aged waste recovered from dump sites

Parameter	Unit	Present study			*India [43]*	*China [7]*
		S1 (n=3)	**S2 (n=3)**	**S3 (n=3)**		
HHV (Exp)	MJ/kg	20.47± (2.87)	16.83± (1.58)	11.09 ± (0.71)	10.7	44.75 ± 1.18
HHV (Th)	MJ/kg	22.5	19.63	11.81		

4. Conclusion

Developing countries are designing policies to improve waste management outcomes. Old landfills are resource reservoirs for future energy generation. Reclamation of the waste material from these landfills increases the life of the landfill and reduces the usage of non-renewable energy sources in energy production. Composition and characteristics of aged waste play a key role in designing the treatment systems for waste recovered from landfill. Systematic approach followed in this study provides an insight in developing a waste characterization study plan for landfills in different urban cities across the globe. In the present study, plastic (waste plastic bags and foils) and textile waste are major components of the aged waste recovered from landfill. The moisture content and the percentage of contamination (soil type material) increased with the age of the waste. The proximity and energy content analysis highlights that the pre-cleaning techniques such as cleaning, drying, and sorting, must be implemented to remove the impurities on the surface of the recovered waste feed stock. Comparing the physio-chemical characteristics of landfill mined waste with process input criteria, incineration is best possible alternative. Thermal conversion treatment technologies options (gasification, pyrolysis, hydrothermal carbonization) can be explored by using comingled feed stocks.

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

VRS has conducted field studies, laboratory analysis, interpretation and was the major contributor in writing the manuscript. MJ and BD analyzed and interpreted results and revised the manuscript. All authors read and approved the final manuscript.

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Authors' information (optional)

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