Energy Recovery Analysis of Perungudi landfill Waste of Chennai, Tamilnadu.

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Abstract: From this study, the quantity, composition, and energy content of waste material in Perungudi dump yard of Chennai, Tamilnadu, India were examined. Based upon the past waste generation data from the documentary evidence and field data was used to predict the quantity of waste generated in future. This study reviews the potential uses of solid wastes generated at the perungudi dump yard as a sustainable energy source. Physical properties of waste sample like specific gravity (Sg), moisture content (MC), dry density, particle size distribution and unit weight of MSW are analyzed using ASTM guidelines. Proximate analysis (For Physical Characteristics) and Ultimate analysis (For elemental Analysis) were analysed in its ash content, volatile matter (Vm) and fixed carbon (Fc). The net calorific energy stored in solid waste was determined using empirical analysis. The element content like carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) value in the solid wastes are derived from standard value of material and this values was substituted into the “Modified Dulong’s” equation to determine the energy content (GCV) of solid waste. Final estimation of energy output was arrived using Gross Calorific Value (GCV) and Net Calorific Value (NCV).

Key Words: Dump yard Solid Waste, Gross Calorific Value (GCV) and Net Calorific Value (NCV), Physical Characteristics, Elemental Analysis.

1. Introduction

An exponential growth in country population size and subsequent of change in life style and migration of population ultimately leads to consumption of goods. These consumption patterns requires to produce more energy results in change in land use pattern, deforestation, intensified agricultural practice and energy use from fossil fuel sources. All of these have contributed to pollution in environment and increasing concentrations of greenhouse gases (GHG). The result of above changes causes tremendous increase in waste in all kind of sources such as residential, commercial, institutional and industrial. India generates approximately 277 million tonnes of solid waste every year from different kinds of sources, based on 2016 estimate which one is accounted of 80 % of waste produces across South Asian countries and contributes 13% of the global waste produces in every year. In urban cities, an individual give rise to at par of 0.80 kg of waste material per day. The accumulated waste generated in urban cities has been 68.80 (MT / Year) during the period 2008. Huge amount of municipal solid waste generated in Chennai, Tamilnadu is collected, transported and unloaded in open dump yard and fraction of waste only treated in engineering/sanitary landfill. The demerits associated with these types are (i) release of high emission density of methane (CH₄) gas and (ii) large quantity of leachate. Landfills are major source of biogas due to the anaerobic fermentation condition which consists 60% of methane (CH₄) by its volume and carbon dioxide (CO₂). By means of Power Reactor Innovative Small Module (PRISM) separator it is attainable to recover the CH₄ by separating carbon dioxide (CO₂). The final outcome of gas is used as natural gas used for electricity generation [11].

There are many options available for transforming landfill gas (LFG) into energy and according to the use it is categorised as Electricity Generation, Direct Use of Medium-Btu Gas, and Renewable Natural Gas [14]. The MSW processed in landfill is accounted the third largest man made source of methane
(CH₄) emissions which contributing 11% of global CH₄ emissions [12]. In aerobic decomposition stage of landfill decomposition process generate a meagre amount of methane. In later stage of anaerobic fermentation, due to methanogen activities, the solid waste generates methane for years, even after landfill closed. A leachate produces in dump yard has been analysed as a substrate for Bio-Electrochemical Systems and Microbial Fuel Cell for generation of electricity and it provides opportunities for resource recovery from landfill decomposed product of leachate. In Bio-Electrochemical Systems treatment process the biological compounds presents in leachate can be converted to electrical energy with the aid of microbial interaction with solid electron acceptors and donors. …

Nutrients and water present in leachate can be recovered through filter using a reverse osmosis flat sheet membrane module [2]. Heavy Metals in leachate can also be recapturing through the approaches of solvent extraction, precipitation, electrolysis from the secondary sources but these recovery processes may affects the concentrations of metal values [7]. Microbial Fuel Cell (MFC) is a bio-electro-chemical system (BES) to treat leachate and it transform chemical energy to electrical energy contained in an biological substrate directly by means and can produce clean energy [8] [10] and it is productive as a source of energy and decreases biological matter in leachate [5]. The aim of study is to analyse the energy content of municipal solid waste (MSW) in Perungudi dump yard which deposited 6000 MT per day. The significant of study is to determine the energy content of solid waste on the basis of both dry and wet weight basis for interpretation purpose whereas the earlier studies only consider the dry weight basis only.

2. Study Area

The greater Chennai corporation of Tamil nadu state is the fourth largest metropolitan corporation in India and located on the eastern coast lane (Latitude 13° 07’ N and Longitude 80° 16’ E). The Total geographical area of the corporation is 174 sq.km with a current population of nearing 1.10 crore (2021). The city has achieved the status of Mega city by National Productivity Council (2005). The current solid waste generation from different sources of Chennai has attained in the range of 600 to 6000 tpd within last two decades and its per capita production rate is 0.60 kg/day. Implementation of Municipal Solid Waste Management (MSWM) is the major activity of Greater Chennai Corporation. It Involves: cleaning-collection-transportation-and disposal of Municipal Solid Waste of the city

The perungudi dumping yard is 9non-engineered low lying dump site and located in the southern portion of Chennai city which is installed in 1987 and operated from 1992. The Dump yard spread over of 800acres out of which 350 acres are using for dumping purpose and the nature of land is marshy land. Perungudi sewage treatment plant (STP) is located abutting to the dumpsite where the discharges the outflow within the proximate distance from dumpsite. The city experiences the Sub-tropical condition with elevation of 9.0 m above mean sea level (MSL). The average minimum and maximum temperature is recorded as 21°C & 38°C respectively. The total mean annual rain fall is 1308 mm and maximum/minimum monthly rain fall of 1088 mm/0.00 mm are observed. The mean monthly relative humidity is recorded as 67.44 % with minimum of 58 % and maximum of 84 % are witnessed by Indian Meteorological Department (IMD). The mean wind speed of location is 4km/hr in November and 1 km/hr in May. The potential open water evaporation is 1960 mm. Rainfall is appeared to be more in related to evapo-transpiration in October to December and vice versa in January to September. The significant of Dump yard is placed towards the northern limit of immense topographic depression termed as the pallikarai which one is major catchment area of Chennai.
The boundary of the dump yard is surrounded by western side of Buckingham canal is about 1.5 to 2.0 km and 3 km west by coastline of Bay of Bengal. It is situated in the low lying marsh land of pallikaranai which extends in the area of 40 Sq.-km with length of 10 Km from north to south and width of 4 Km from west to east. This marsh land is acts as major flood control system and water holding area of the Chennai city.

3. Data collection

Data is collected from site analysis as a primary source depicts in Figure. 1 and literature and previous studies as secondary sources. A typical value of moisture content shown in Table 1 is used for proximate analysis. Typical energy value of MSW shown in table 2 is used to calculate the total energy and specific energy in wet and dry weight basis and ash free basis. A Typical value of chemical contents is shown in Table 3 is used for ultimate analysis.

Table 1. Typical value of moisture (MC) and ash content of municipal solid waste (MSW).

| S.No. | Constituents    | Moisture | Ash | S.No. | Component      | Moisture | Ash |
|-------|-----------------|----------|-----|-------|----------------|----------|-----|
| 1.    | Food Waste      | 70%      | 5%  | 8.    | Garden Waste   | 60%      | 4.5%|
| 2.    | Paper           | 6%       | 6%  | 9.    | Wood           | 20%      | 1.5%|
| 3.    | Card board      | 5%       | 5%  | 10.   | Misc organics  | 25%      | 5   |
| 4.    | Plastics        | 2%       | 10% | 11.   | Glass          | 2%       | 0   |
| 5.    | Textiles        | 10%      | 2.5%| 12.   | Tin Cans       | 3%       | 0   |
| 6.    | Rubber          | 2%       | 10% | 13.   | Non-Ferrous    | 2%       | 0   |
| 7.    | Leather         | 10%      | 10% | 14.   | Ferrous Metal  | 3%       | 0   |
Table 2. Typical Value of Inert Residue and Energy content of solid wastes.

| S.No. | Constituents            | Inert Residue (%) | Energy (Kj/Kg) |
|-------|-------------------------|-------------------|----------------|
|       |                         | Min-Max           | Ideal          | Min-Max        | Ideal        |
| 1.    | Food/organic Waste      | 2-5               | 5              | 3500-7000      | 4650         |
| 2.    | Paper                   | 4-8               | 6              | 11600-18600    | 16750        |
| 3.    | Card board              | 3-6               | 5              | 13950-17450    | 16300        |
| 4.    | Plastics                | 6-20              | 10             | 27900-37200    | 32600        |
| 5.    | Textiles                | 2-4               | 2.5            | 15100-18600    | 17450        |
| 6.    | Rubber                  | 8-20              | 10             | 20900-27900    | 23250        |
| 7.    | Leather                 | 8-20              | 10             | 15100-19800    | 17450        |
| 8.    | Garden Trimmings        | 2-6               | 4.5            | 2300-18600     | 6500         |
| 9.    | Wood                    | 0.6-2             | 1.5            | 17450-19800    | 18600        |
| 10.   | Glass                   | 96-99             | 98             | 100-250        | 150          |
| 11.   | Tin Cans                | 96-99             | 98             | 250-1200       | 700          |
| 12.   | Non-Ferrous             | 90-99             | 96             | -              | -            |
| 13.   | Ferrous Metal           | 94-99             | 98             | 250-1200       | 700          |
| 14.   | Dirt, Ashes, Brick etc  | 60-80             | 70             | 2300-11650     | 7000         |
| 15.   | MSW                     | -                 | -              | 9300-12800     | 10500        |

Table 3. Typical level of Chemical Composition of municipal solid waste.

| S.No. | Constituents               | C   | H   | O   | N   | S   | Ash |
|-------|----------------------------|-----|-----|-----|-----|-----|-----|
| 1.    | Food/organic Waste         | 48  | 6.4 | 37.6| 2.6 | 0.4 | 5   |
| 2.    | Paper                      | 43.5| 6   | 44  | 0.3 | 0.2 | 6   |
| 3.    | Card board                 | 44  | 5.9 | 44.6| 0.3 | 0.2 | 5   |
| 4.    | Plastics                   | 60  | 7.2 | 22.8| -   | -   | 10  |
| 5.    | Textiles                   | 55  | 6.6 | 31.2| 4.6 | 0.15| 2.5 |
| 6.    | Rubber                     | 78  | 10  | -   | 2   | -   | 10  |
| 7.    | Leather                    | 60  | 8   | 11.6| 10  | 0.4 | 10  |
| 8.    | Garden Trimmings           | 47.8| 6   | 38  | 3.4 | 0.3 | 4.5 |
| 9.    | Wood                       | 49.5| 6   | 42.7| 0.2 | 0.1 | 1.5 |
| 10.   | Dirt, Ashes, Brick etc     | 26.3| 3   | 2   | 0.5 | 0.2 | 68  |

4. Materials and Methodology

4.1. Physical and Chemical Composition of Waste
Solid waste components were explored in terms of (i) Specific weight, (ii) Moisture Content, (iii) density, (iv) energy content (v) volatile matter and chemical composition in terms of Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur and Ash. To compare the properties of solid waste in different conditions, two methods such as “dry basis and “ash-free dry basis” is used to determine the energy content of solid waste.

4.2. Determination of Composition and Quantification of Waste
MSW composition was identified by physical segregation and compliance of collected wastes. The random sampling technique is used to collect the sample. Each container of waste was weighed using calibrated scale then its contents are emptied, segregated, and grouped into according to each class of waste. The quantification of solid waste was done using calibrated weighing scale on the basis of dry state and discarded (wet) basis to assess its reuse value like energy generation, compost etc., It also provide an information to analysis and design of land fill system, handling and transported procedures from source to disposal site and establishing the recyclable materials.
4.3. Characteristics of Solid Waste: Proximate Analysis

In this study, American Society for Testing and Materials (ASTM) procedures were used to analyse the characteristics of the MSW. These methods are discussed below: [13].

4.3.1 Moisture Content (MC)

The moisture content of waste material is an indicator for calculating energy content. Each segregated constituent of material was weighed and placed in an oven for drying for 24 hrs at 105°C and samples were cooled in desiccators and then reweighed. The wet content as a (%) was determined from the following relationship in dry and wet basis as follows:

\[
\text{Wet weight of moisture content} = \frac{100(W_w - W_d)}{W_w}
\]

(1)

\[
\text{Dry weight of moisture content} = \frac{100(W_w - W_d)}{W_d}
\]

(2)

An ideal range of moisture content value is 20 to 45% and it represents the extreme condition of waste characteristics in a dry climate and in the rainy season of a region having heavy rainfall. In general moisture content of waste more than 45% are unusual. Moisture content is a significant factor in the economic feasibility of incineration processes through energy should be supplied for evaporation of wet content of material and in increasing the temperature of the water vapour.

4.3.2. Density

Density of solid waste indicates information about predicting capacity of storage volume including in the level of (I) as discarded at source (ii) process of compaction in a collection tank and (iii) process of compaction within a landfill cell. Operation efficiency of landfill requires compaction of waste to optimum density after it is placed. The typical value of solid waste density in India is in the range of 450 – 500 Kg/m³. The density of material is based upon degree of compaction, moisture content, and its physical shape. Relatively increase in proportion of non-biodegradable material such as glass, ceramics, ashes and metals will leads to increase in density. The ideal range of density of raw wastes in the range of 115 to 180 Kg/m³ in developed countries which is due to shape of the material container. In compacted condition, the density of landfill waste is in the range of 300 to 900 Kg/m³. A decrease in volume of 75% is frequently achieved with normal compaction condition. Determination of the density of waste sample was computed using the formula:

\[
\text{Density} = \frac{\text{Mass}}{\text{Volume}} \text{ in Kg/m}^3
\]

4.3.3. Calculation of Volatile Matter (Vₘ), Ash Content and Biodegradable Fraction (Bₖ) and Fixed Carbon (Fₖ) and fusing point of Ash:

The air-dried sample and crucible was put into the muffle furnace and ignited at 550°C for half an hour, till the ash was charred to a clear white colour. The crucible plus ash was separated from the muffle furnace cooled for at least half an hour and carefully weighed on a calibrated balance. It is used as a measure of the bio-degradability of the organic content. The quantity of volatile matter with dry basis was computed by difference between the dry weight of solid waste and the weight of the residue after ignition.
Volatile Matter ($V_s$) @ 925°C / 7 min = \frac{\text{Loss In Weight Due To Volatile Matter}}{\text{Initial Weight Of Solid Waste}} \times 100 \quad (4)

\begin{align*}
V_s &= \frac{m_1 - m_2}{m} \times 100 \quad (5)
\end{align*}

Where $m_1, m_2$ and $m$ are weight of Initial, dry state and residue after ignition of solid waste respectively. However, some material could be highly volatile but low biodegradable, hence use of volatile could be misleading.

Ash content is the quantity of residue obtained after ignition of material and calculated as follows:

\[
\% \text{ ash (dry basis)} = \frac{\text{Weight of Residue after Ignition} (W_{RI})}{\text{Weight of Dry Solid Waste} (W_d)} \times 100
\]

Not all organic materials are easily and equally biodegradable. Estimation of biodegradable content in solid waste using in the following empirical relationship:

\[
\text{Estimation of Biodegradable Fraction} (B_F) = 0.83 - 0.028 L_c
\]

Where $L_c$ is the ignition content of volatile sample expressed as % of dry state and 0.83 and 0.028 are empirical constant. Fixed carbon content gives the information about the amount of formation of char in the thermo-chemical conversion process which one is the solid combustible residue that remains after the volatile matters drive away apart from ash and moisture and it was burned as solid substances in the combustion process [6].

\[
\text{Fixed carbon} (\%) = 100 - [\text{Moisture Content} + \text{Volatile Matter} + \text{ash content}] \text{ in } \%
\]

4.3.4 Fusing point of Ash

The resulting non-biodegradable waste after burning at particular temperature of solid waste which consists of minerals in the form of solid clinker (slag) by fusion and agglomeration. The ideal value fusing point of Ash is in the range of 1100 – 1200°C [3].

4.3.5 Calorific/ Energy Value

Energy recovery from waste as an integral part of the MSW management which is defined as calorific value (CV). The energy content of waste material is determined by amount of heat generated from combustion of material which is completely burned and is expressed as Kj/Kg [9]. The energy content of solid waste is composed of numerous parameters such as physical characteristics of the waste, moisture content (MC) and ash content in % [1]. In general, Calorimetric measurement used to determine the energy content of Municipal Solid Waste. At laboratory scale, calorific value is determined by using a bomb calorimeter in dry state at temperature of 25°C. If experimental temperature is lower than the boiling point of water, the combustion of water remains in the liquid state. In combustion stage, the temperature of gas is remains above 100°C, in which the water is in the vapour state. Calorific value of solid wastes plays an important role to determine the potential energy recovery in Refuse Derived Fuel (RDF) from waste and its utilisation in waste to energy plant.

4.4. Energy Content of Dry & Ash free Dry Basis.

The energy content of the sample of solid waste material on both ash-free dry basis and dry basis was calculated by using the data on typical energy values of various components.

\[
\text{Dry Basis (KJ/Kg)} = \frac{\text{Energy as discarded}}{100 - \text{Moisture Content (MC)}} \times 100
\]

\[
\text{Energy as discarded} = \text{Energy as discarded} \times \frac{100}{100 - \text{Moisture Content (MC)}}
\]
Ash-free dry basis (KJ/kg) = Energy as discarded \times \frac{100}{100 - \text{Ash content-MoistureContent (MC)}} \quad (10)

4.5. Computation of Lower Heating Value and Higher Heating Value.

4.5.1. Higher Heating Value / Gross Calorific Value.

The Higher Heating Value of MSW is known as the amount of heat produced by fully combustion of a mass unit of material at constant volume in an oxygen atmosphere considering that both the water accommodated in the sample and the water generated from the combined hydrogen, remains in liquid form [4]. The HHV is useful to calculate the latent heat from Vaporisation of liquid in the combustion materials which one is helpful to calculate the values of fuels condensation of the reaction products is practical.

\[
\text{HHV on as discarded basis} = \frac{\text{Total Energy}}{\text{Total Discarded mass}} \quad (11)
\]

\[
\text{HHV on dry basis} = \frac{\text{Total Energy}}{\text{Dry mass}} \quad (12)
\]

Dulong’s Formula

In the absence of energy values: HHV (KJ/Kg) = 32851C + 141989 \left( H - \frac{O}{8} \right) + 9263 S \quad (13)

Where C - Carbon, H - Hydrogen, O - Oxygen, S - Sulphur.

4.5.2 Lower Heating Value (LHV) / Net Calorific Value

The Lower Heating Value is defined as the process of energy content released from the combustion of the MSW green components in an incinerator and it can be used to represent the energy content of solid waste. The energy content of solid waste can be quantified by using a full scale boiler as a calorimeter, a laboratory bomb calorimeter, and calculation based on empirical models.

\[
\text{LHV on as discarded basis} = \frac{\text{HHV on an discarded basis} \times \text{Latent Heat}}{\text{Total mass}} \quad (14)
\]

\[
\text{LHV on dry basis} = \frac{\text{Total Energy} - \text{Water from net Hydrogen} \times \text{Latent Heat}}{\text{Dry mass}} \quad (15)
\]

4.6. Elemental Analysis or Ultimate Analysis

Ultimate analysis is used to determine the Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur and Ash from solid waste. The finding of the analysis is used to characterize the composition of the organic matter in wastes. This is important for determining C/N ratio for biological decomposition.

4.6.1 Dulong’s model

\[
\text{Lower Heating Value} = 81C + 342.5 \left( H - \frac{O}{8} \right) + 22.5S - 6(W + 9H) \quad (16)
\]

Where C, O, H, S and W is Carbon, Oxygen, Hydrogen, Sulphur and Moisture content in (wt %).

5. Result and Discussion

Table 4 show the result of moisture content which is derived from mass and density of the waste material.
Table 4. Moisture content of solid waste (Wet/Dry Weight Basis)

| Components          | Wet Weight (kg) | Dry Weight (Kg) | MC - Wet weight Basis | MC – Dry Weight Basis | Typical Density (Kg/m³) |
|---------------------|-----------------|-----------------|-----------------------|-----------------------|-------------------------|
| Biodegradable Waste |                 |                 |                       |                       |                         |
| Food Waste          | 28.7            | 8.61            | 70                    | 233.33                | 290                     |
| Garden Waste        | 18.9            | 7.56            | 60                    | 150.00                | 105                     |
| Recyclable Material |                 |                 |                       |                       |                         |
| Paper               | 12.00           | 11.16           | 7.00                  | 7.52                  | 85                      |
| Textiles            | 8.00            | 7.20            | 10.00                 | 11.11                 | 65                      |
| Leather             | 2.00            | 1.74            | 13.00                 | 14.94                 | 160                     |
| Rubber              | 0.80            | 0.80            | -                     | 0.00                  | 130                     |
| Wood                | 1.00            | 0.40            | 150.00                | 240                   |                         |
| Non- Biodegradable Waste |          |                 |                       |                       |                         |
| Glass               | 4.00            | 3.90            | 2.50                  | 2.56                  | 195                     |
| Plastics            | 8.00            | 7.60            | 5.00                  | 5.26                  | 65                      |
| Metals              | 2.00            | 1.96            | 2.00                  | 2.04                  | 320                     |
| C & D Waste         | 12.6            | 12.34           | 2.00                  | 2.10                  | 480                     |
| Total               | 100             | 63.27           | **36.73**             | **58.05**             |                         |

Table 5 shows the content of volatile material and volume of material in wet and dry weight basis based on this fixed carbon and biodegradable fraction is arrived.

Table 5. Volume and Volatile Matter of Solid Waste (Wet and Dry Weight Basis)

| Components          | Typical Density (Kg/m³) | Wet Weight (kg) | Dry Weight (Kg) | Wet Volume | Dry Volume | Typical Ash Content | % Volatile Matter-Wet | % Volatile Matter-Wet |
|---------------------|-------------------------|-----------------|-----------------|------------|------------|---------------------|-----------------------|-----------------------|
| Food Waste          | 290                     | 28.7            | 8.61            | 0.098      | 0.03       | 5.0                 | 69.17                 | 150                   |
| Garden Waste        | 105                     | 18.9            | 7.56            | 0.18       | 0.072      | 4.5                 | 59.24                 | 7.12                  |
| Paper               | 85                      | 12.00           | 11.16           | 0.14       | 0.131      | 6.0                 | 6.50                  | 10.65                 |
| Textiles            | 65                      | 8.00            | 7.20            | 0.12       | 0.11       | 2.52                | 9.32                  | 14.29                 |
| Leather             | 160                     | 2.00            | 1.74            | 0.12       | 0.0108     | 10.00               | 17.00                 | 4.75                  |
| Rubber              | 130                     | 0.80            | 0.80            | 0.0006     | 0.0061     | 10.00               | 11.50                 | 161.50                |
| Wood                | 240                     | 1.00            | 0.40            | 0.0041     | 0.0017     | 1.50                | 0.50                  | 2.75                  |
| Glass               | 195                     | 4.00            | 3.90            | 0.0205     | 0.02       | 0.00                | 1.50                  | 1.56                  |
| Plastics            | 65                      | 8.00            | 7.60            | 0.123      | 0.117      | 10.00               | 5.25                  | 5.58                  |
| Metals              | 320                     | 2.00            | 1.96            | 0.0065     | 0.0061     | 0.00                | 1.00                  | 1.04                  |
| C & D Waste         | 480                     | 12.6            | 12.34           | 0.0262     | 0.026      | 68.0                | 6.40                  | 6.61                  |
| Total               | **100.00**             | **63.27**       | **0.8389**       | **0.5307** |            |                     |                       |                       |
Wet Density = 100/0.8389 = 119.20 Kg/m³ Dry Density = 100/ 0.5307 = 188.43 Kg/m³

Volatile matter as on Wet Weight Basis = 35.78% Volatile Matter as on Dry Weight Basis = 57.12%

Fixed Carbon (Weight % on Wet Weight Basis) = 22.49% Loss of Ignition, (%) = 36.73%

Estimation of Biodegradable Fraction ($B_f = 0.83 – 0.028 Lc$ = 0.20

Table 6 shows the results of Total energy, specific energy and energy value of waste materials in wet and dry weight basis.

### Table 6. Total and Specific Energy of Solid Waste (Wet and Dry Weight Basis)

| Components      | Wet Weight In (Kg) | Dry Weight In (Kg) | Typical Energy Value | Total Energy (KJ) Wet Basis | Total Energy (KJ) Dry Basis |
|-----------------|--------------------|--------------------|----------------------|------------------------------|-----------------------------|
| Food Waste      | 28.7               | 8.61               | 4650                 | 133455                       | 1149047                     |
| Garden Waste    | 18.9               | 7.56               | 6500                 | 122850                       | 49140                       |
| Paper           | 12.00              | 11.16              | 16750               | 201000                       | 186930                      |
| Textiles        | 8.00               | 7.20               | 17450               | 139600                       | 125640                      |
| Leather         | 2.00               | 1.74               | 17450               | 34900                        | 30363                       |
| Rubber          | 0.80               | 0.80               | 23250               | 18600                        | 18600                       |
| Wood            | 1.00               | 0.40               | 18600               | 18600                        | 7440                        |
| Glass           | 4.00               | 3.90               | 150                 | 600                          | 585                         |
| Plastics        | 8.00               | 7.60               | 32600               | 260800                       | 247760                      |
| Metals          | 2.00               | 1.96               | 700                 | 1400                         | 1372                        |
| C & D Waste     | 12.6               | 12.34              | 700                 | 8820                         | 8638                        |
| Total           | **100.00**         | **63.27**          | **1108025**         | **1825515**                  |                             |

Case 1: Discarded Basis

Gross calorific Value (GCV)/ Higher Heating Value (HHV) on as discarded basis KJ/kg = 11080

Latent Heat of Vaporisation of Waste = 2420 KJ/kg.

H₂O from Net Hydrogen = [5.77 – (32.96/8)] x 9 = 14.85.

Lower Heating Value (LHV) on as discarded basis = (1108025 – 14.85 x 2420)/100 = 10721 KJ/kg

Case 2: Dry Weight Basis

Gross Calorific Value/ Higher Heating Value on as dry basis KJ/kg = 28853 KJ/kg.

H₂O from Net Hydrogen = [3.6 – (19.48/8)] x 9 = 10.46.

Lower Heating Value (LHV) on as Dry Weight basis = (1825515 – 10.46 x 2420)/100 = 180002 KJ/kg.

Table 7 shows the calculation of Energy content of dry and wet weight basis. Based upon the result Higher heating value and lower heating values are arrived on an ash free basis.
Table 7. Energy Content of On an Ash Free (Wet and Dry Weight Basis)

| Components        | Wet Weight (Kg) | Dry Weight (Kg) | Typical Ash Content | Energy Content on an Ash free wet Basis | Energy Content on an Ash free dry Basis |
|-------------------|-----------------|-----------------|---------------------|----------------------------------------|----------------------------------------|
| Food Waste        | 28.7            | 8.61            | 5.0                 | 30039                                  | 117770                                 |
| Garden Waste      | 18.9            | 7.56            | 4.5                 | 29784                                  | 116198                                 |
| Paper             | 12.00           | 11.16           | 6.0                 | 30564                                  | 121046                                 |
| Textiles          | 8.00            | 7.20            | 2.52                | 28814                                  | 110363                                 |
| Leather           | 2.00            | 1.74            | 10.00               | 32857                                  | 136200                                 |
| Rubber            | 0.80            | 0.80            | 10.00               | 32857                                  | 136200                                 |
| Wood              | 1.00            | 0.40            | 1.50                | 28338                                  | 107578                                 |
| Glass             | 4.00            | 3.90            | 0.00                | 27667                                  | 103733                                 |
| Plastics          | 8.00            | 7.60            | 10.00               | 32857                                  | 136200                                 |
| Metals            | 2.00            | 1.96            | 0.00                | 27667                                  | 103733                                 |
| C & D Waste       | 12.6            | 12.34           | 68.0                | -                                      | -                                      |
| Total             | 100.00          | 63.27           | 100.00              | 301445                                 | 1189023                                |

Case 3: Ash Free Wet Basis

Gross calorific Value (GCV)/ Higher Heating Value on Ash free (Wet) Basis KJ/kg = 3016 KJ/kg

Lower Heating Value (LHV) on as discarded basis = (301455 − 14.85 x 2420)/100 = 2655 KJ/kg.

Case 4: Ash Free Dry Basis

Gross calorific Value (GCV)/ Higher Heating Value on Ash free (dry) basis KJ/kg = 18793 KJ/kg.

Lower Heating Value (LHV) on as Dry Weight basis = (1189023 − 10.46 x 2420)/100 = 11637 KJ/kg.

Table 8 shows the outcome of chemical components of solid wastes in dry and wet weight basis to arrive the chemical formula of solid waste.

Table 8. Chemical Components of Solid Waste in Wet and Dry basis

| Component        | Carbon (C) | Hydrogen (H) | Oxygen (O) | Nitrogen (N) | Sulphur (S) | Ash |
|------------------|------------|--------------|------------|--------------|-------------|-----|
|                  | Wet        | Dry          | Wet        | Dry          | Wet         | Dry |
| Food Waste       | 13.78      | 4.13         | 1.84       | 0.55         | 10.79       | 3.24 |
| Garden Waste     | 8.22       | 3.29         | 1.13       | 0.45         | 8.32        | 3.33 |
| Paper            | 5.28       | 4.91         | 0.71       | 0.66         | 5.35        | 4.98 |
| Textiles         | 4.80       | 4.32         | 0.58       | 0.52         | 1.82        | 1.64 |
| Leather          | 1.10       | 0.96         | 0.13       | 0.11         | 0.62        | 0.54 |
| Rubber           | 0.62       | 0.62         | 0.08       | 0.08         | -           | -    |
| Wood             | 0.60       | 0.24         | 0.08       | 0.03         | 0.12        | 0.05 |
| Glass            | 1.91       | 1.86         | 0.24       | 0.23         | 1.52        | 1.48 |
| Plastics         | 3.96       | 3.76         | 0.48       | 0.46         | 3.42        | 3.25 |
| Metals           | 0.97       | 0.95         | 0.13       | 0.13         | 0.75        | 0.74 |
Energy Value using Dulong’s Model:

Higher calorific Value on wet weight basis: 3642.50 KJ/kg and

Higher calorific Value on Dry weight basis: 2149 KJ/kg.

Table 9 shows the moisture content value in terms of hydrogen and oxygen.

**Table 9. Convert Moisture content in to Hydrogen and Oxygen**

| Component | Wet Basis | Dry Basis |
|-----------|-----------|-----------|
| Hydrogen  | 4.08 Kg   | 6.50 Kg   |
| Oxygen    | 32.65 Kg  | 51.60 Kg  |

Table 10 shows the value of Molar composition of the element

**Table 10. Compute Molar Composition of the Element**

| Component | Moles wet basis | Moles Dry Basis | % by Mass Wet | % by Mass Dry | Molar Value Kg/Vol | Moles wet basis | Moles Dry Basis |
|-----------|-----------------|-----------------|---------------|---------------|-------------------|----------------|----------------|
| Carbon    | 3.7102          | 2.3564          | 0.60          | 0.49          | 12.01             | 3.7102         | 2.3564         |
| Hydrogen  | 3.60            | 3.60            | 0.05          | 0.06          | 1.01              | 3.5644         | 3.5644         |
| Oxygen    | 19.48           | 19.48           | 0.26          | 0.33          | 16.00             | 1.2175         | 1.2175         |
| Nitrogen  | 0.67            | 0.67            | 0.01          | 0.01          | 14.01             | 0.0478         | 0.0478         |
| Sulphur   | 0.013           | 0.013           | 0.00          | 0.00          | 32.06             | 0.0004         | 0.0004         |
| Total     | 74.43           | 58.17           |               |               |                   |                |                |

Table 11 shows the chemical formula for solid waste components with and without sulphur content. Also, the Table.12 illustrates the Summary of Proximate and Ultimate Analysis.

**Table 11. Chemical Formula for Solid Waste Components with and without Sulphur**

| Component | Moles wet basis | Moles Dry Basis | Wet Basis | Dry Basis |
|-----------|-----------------|-----------------|-----------|-----------|
| Carbon    | 3.7102          | 2.3564          | 9275.60   | 5890.92   |
| Hydrogen  | 3.5644          | 3.5644          | 8910.89   | 8910.89   |
| Oxygen    | 1.2175          | 1.2175          | 3043.75   | 3043.75   |
| Nitrogen  | 0.0478          | 0.0478          | 119.56    | 119.56    |
| Sulphur   | 0.0004          | 0.0004          | 1.01      | 1.01      |

Chemical Formula with Sulphur (Wet Basis) \( C_{9275.60}H_{8910.89}O_{3043.75}S_{119.56} \)

Chemical Formula without Sulphur (Wet Basis) \( C_{77.56}H_{74.57}O_{25.47} \)

Chemical Formula with Sulphur (Dry Basis) \( C_{5890.92}H_{8910.89}O_{3043.75}S_{119.56} \)

Chemical Formula without Sulphur (Dry Basis) \( C_{49.30}H_{74.57}O_{25.47} \)
Table 12. Summary of Proximate and Ultimate Analysis

| S.No | Components                  | Wet Weight Basis | Dry Weight Basis |
|------|-----------------------------|------------------|------------------|
| 1    | Weight                      | 100 Kg           | 63.27 Kg         |
| 2    | Moisture Content            | 36.73 %          | 58.05 %          |
| 3    | Volume                      | 0.8849 m³        | 0.3307 m³        |
| 4    | Density                     | 119.20 Kg/m³     | 188.43 Kg/m³     |
| 5    | Volatile Matter             | 35.78%           | 57.12%           |
| 6    | Fixed Carbon                | 22.49%           | -                |
| 7    | Biodegradable Fraction      | 0.20             | -                |
| 8    | Total Energy                | 1108025 KJ/kg    | 1825515 KJ/kg    |
| 9    | Specific Energy             | 11080 KJ/kg      | 18255 KJ/kg      |
| 10   | Energy                      | = 17513 KJ/kg    | 43516 KJ/kg      |
| 11   | Energy Value (Dulong’s Model)| 3642.50 KJ/kg   | 2149 KJ/kg       |
| 12   | On as Ash Free Basis        |                  |                  |
| 13   | Total Energy                | 301445 KJ/kg     | 1189023 KJ/kg    |
| 14   | Specific Energy             | 3014 KJ/kg       | 18792 KJ/kg      |
| 15   | Energy                      | 517324 KJ/kg     | 3246032 KJ/kg    |
| 16   | Discarded Basis HHV/GCV     | 11080 KJ/kg      | LHV/NCV 10721 KJ/kg |
| 17   | Dry Weight Basis HHV/GCV    | 28853 KJ/kg      | LHV/NCV 180002 KJ/kg |
| 18   | Ash Free Wet Basis HHV/GCV  | 3016 KJ/kg       | LHV/NCV 2655 KJ/kg |
| 19   | Ash Free Dry Basis HHV/GCV  | 18793 KJ/kg      | LHV/NCV 1163 KJ/kg |
| 20   | Components                  | Carbon Hydrogen Oxygen Nitrogen Sulphur Ash |
|      | Wet Basis                   | 44.56 5.77 32.96 1.31 0.23 13.57 |
|      | Dry Basis                   | 28.30 3.6 19.48 0.67 0.013 6.11 |
| 21   | Wet Chemical Formula with Sulphur | C_{9275.66}H_{8910.89}O_{3043.75}N_{119.56}S |
|      | Basis                       | C_{77.62}H_{74.57}O_{25.47}N |
| 22   | Dry Chemical Formula with Sulphur | C_{5890.93}H_{4910.89}O_{3043.75}N_{119.56}S |
|      | Basis                       | C_{49.30}H_{74.57}O_{25.47}N |

6. Conclusion

The purpose of this study was to analyse the repercussion of composition of waste on the report of content of energy in wet, dry and discarded weight basis. The waste of Energy content samples evaluated from the analysis is above than the 7,000 KJ/kg which is ideal calorific value of materials required for establishing an incineration plant with energy recovery. The typical range of net electrical energy that can be produced is about 500 to 600 kWh of electricity per ton of waste incinerated. Thus, the incineration of about 6000 metric tons per day of waste produced by Chennai city will generate about 3272 MWh of electrical energy which one is compared with average calorific value of the recovered landfill waste ranged from 10.4 to 21.8 MJ/kg in Indian scenario [15]. Furthermore, suitable technologies must be studied for extracting energy from these types of waste. Conversion of waste to energy can solve the problem of waste disposal, recover waste energy, and be used in generating electricity, fuels and gases. Pollution emissions may decrease using appropriate control equipment, sites for hygienic land filling and the amount of green gas emissions will decrease as well. In making a final step to WtE, a further study is necessary to evaluate the economics and environmental impact of the types and location of WtE plants to be deployed.
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