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An Analysis of Treatment Options for Solid Waste by Characterization and Composition Study-A Case of Jaipur City

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Abstract:
Solid waste generation is increasing rapidly due to rapid urbanization, industrialization and population growth. Handling of Solid Waste is one of the major problem which is being faced by all over the world. In most of the developing countries mixed waste is directly disposed, without any treatment, to unscientific open dumping sites that increases environmental pollution and also poses risk to human health, ground water and soil quality. The present study was done on Jaipur city to assess the characteristics and composition of waste that helped in finding suitable treatment option for solid waste of Jaipur city. The results revealed that high moisture content (57.75%.) of combustible part of waste, High amount of biodegradable waste(42.7%) and C/N ratio(22) are present in studied sample of solid waste which meets all the criteria required for anaerobic digestion. The amount of biogas that can be generated from anaerobic digestion of solid waste was calculated as 0.1434 m^3/Kg. It was found that Jaipur city generates 1383 tones of waste per day which can produce 4.48 MW of electricity on anaerobic digestion.
Key words: Anaerobic digestion, Moisture content, Bio gas, Solid waste, biodegradable.

1. INTRODUCTION

Solid waste can be defined as any unwanted item or refuse which is produced by various human activities and discarded by public. Solid waste generally consist of food & yard waste, plastic, paper, construction & demolition waste. Solid waste generation rate and composition of solid waste vary from place to place and it mainly depends on some factors like public attitude, Income level and geographic location.

In most of the developing countries percentage of wet waste and inert waste is high and landfilling is the only option to handle the waste. **Visvanathan et.al**.[14] carried out a study in 2001 shows that disposal of waste is a serious problem in Asia due to unorganized and uncontrolled urban growth. Also there is lack of money and trained men power for SWM system. According to them, the waste generated per capita in Asia is around 0.2kg/day to 1.7kg/day. Solid waste is being disposed in open dumping sites in most of the Indian cities which poses a risk for environment **(Mufeed, 2006)[14].** So it is necessary to find out suitable treatment options like recycling, reuse, composting, energy generation so that not only land requirement to dispose the waste will be decreased but also some revenue can be generated from this waste.

By keeping the problems discussed above in mind, this paper presents the analysis of characteristics and composition of solid waste of Jaipur city with special focus on Treatment and processing. All the

functional elements of Solid Waste Management System i.e. collection & storage, Transportation, processing and final disposal of solid waste of Jaipur city were analyzed and it was found that waste treatment and processing is the most neglected part in the system. The amount of waste generated in the Jaipur city was found to be 1383 tonnes per day. Most of the waste is directly dumped, without any treatment, to the unscientific landfill sites namely Mathuradaspura, Sewapura and Langariyawas which pollutes soil and ground water quality and also poses risk to health of human and environment. **Abhishek Gautam et.al.(2011)** assessed the Ground Water Quality at Municipal Solid Waste Dumping Site- Sewapura, Jaipur[10]. The ground water in the study area is being polluted by percolation of toxic substances into it that may make it completely unfit for the purpose of drinking and irrigation. **Anirudh Sahni et.al.(2011)** assessed the Heavy Metal Toxicity in Soils nearby Municipal Solid Waste dumping site[9].

Based on the present situation of SWM system of Jaipur City, it became necessary to find out a suitable treatment option. Waste processing shall be aimed at minimization of the waste to be landfilled and ensure reduction in landfill space. The proximate and ultimate analysis of waste is required to suggest a suitable treatment process which will also be helpful for authorities to prepare a proper project plan and cost estimation also.

2. MATERIALS AND METHODS

In order to determine elemental composition of solid waste we need to know the physical characteristics of waste. 15 samples (each of 5 Kg) of solid waste are collected during one month from the point of generation of waste, transportation vehicles and different landfill sites of Jaipur City. All the sample were manually separated in different categories

2.1 Moisture Content

Moisture Percentage (M) can be calculated by heating the solid waste at 105^{o}C for 1 hour.

M = [(Wet waste – dry waste)/dry waste] X100

2.2 Ultimate Analysis

Ultimate analysis of waste was performed by using typical values as shown in the table (Tchobanoglous et al 1993)

Table-1 Standard Values of Ultimate analysis of Solid Waste

Component	Moisture %	Carbon %	Hydrogen %	Nitrogen %	Oxygen %	Sulfur %	Ash %
Textile	10	55	6.6	4.6	31.2	0.15	2.5
Plastic	0.2	60	7.2	-	22.8	-	10
Food & yard waste	70	48	6.4	2.6	37.6	0.4	5
Rubber	1.2	78	10	2	-	-	10
Wood	20	49.5	6.0	0.2	0.300	0.0007	1.5
Paper	10.2	43.5	6.0	0.3	44	0.2	6

2.3 Calorific Value

Calorific Value is calculated by using Dulong's formula:

Energy content (in Btu / lb) = 145 C + 610 (H – O / 8) + 40 S + 10 N

Here

C= % by mass of carbon

H= % by mass of Hydrogen

O=% by mass of Oxygen

S=% by mass of sulfur

N=% by mass of Nitrogen

3. RESULTS AND DISCUSSIONS

Table-2 Percentage Composition of various Components of Solid Waste of Jaipur city

Components	Amount of waste in tones	Waste in Percentage by Mass (%)
Paper	76.07	5.5
Textile	27.66	2.0
Plastic	13.83	1.0
Glass	24.89	1.8
Ash & earth materials	625.11	45.2
Food & Yard Waste	590.54	42.7
Rubber	11.06	0.8
Wood	13.83	1.0
Total	**1383**	**100**

3.1 Ultimate Analysis of Combustible Fraction of waste

In order to calculate energy recovery potential and to compute chemical formula of solid waste we need to know the elemental composition of waste.

Table- 3 Elemental Composition of Combustible Part Solid Waste of City

Component	Wet Waste	Dry Waste	Carbon	Hydrogen	Nitrogen	Oxygen	Sulfur	Ash
Textile	2.00	1.80	0.99	0.118	0.082	0.560	0.0027	0.045
Plastic	1.00	0.99	0.594	0.0712	-	0.225	-	0.099
Food & yard waste	42.7	12.81	6.14	0.810	0.380	4.840	0.051	0.64
Rubber	0.8	0.80	0.627	0.080	0.0016	-	-	0.080
Wood	1.00	0.79	0.390	0.047	0.026	0.300	0.0007	0.0118
Paper	5.5	5.20	2.26	0.310	0.0156	2.300	0.010	0.312
Total	**53.00**	**22.39**	**10.990**	**1.4362**	**0.5052**	**8.225**	**0.0644**	**1.1878**

Weight of Moisture = 53-22.39 = 30.61 Kg

Moisture percentage of combustible part of waste = 30.61/53 = 57.75 %

Now we have to convert Moisture Content of Waste into Hydrogen and Oxygen:-

Oxygen = (16/18) X 30.61 = 27.2 kg

Hydrogen = (2/18) X 30.61 = 3.4 kg

Total mass of Hydrogen including H_2O = 1.4362 + 3.4 = 4.83 kg

Total mass of Oxygen including H_2O = 8.225 + 27.2 = 35.425 kg

Table- 4 Mass percent of Elements present in Solid Waste of City

Component	Mass	% by mass
Carbon (C)	10.99	20.73
Hydrogen (H)	4.83	9.11
Oxygen (O)	35.425	66.83
Nitrogen (N)	0.5052	0.95
Sulfur (S)	0.0644	0.121
Ash	1.182	2.24
Total	**53.00**	**100.00**

3.2 Calculation of Calorific Value of Solid Waste:

= 145 X 20.73 + 610 (9.11 – 66.83 / 8) + 40 X 0.121 + 10 X 0.95

= 3481.5 Btu / lb

= 1923.98 KCal/Kg

Net calorific value on 100 Kg basis will be = (1923.98 X 53) / 100

= **1019.70 Kcal/Kg**

From the calculations it was found that because of high moisture content, low calorific value and high percentage of inert waste incineration will not be a good treatment option for solid waste of Jaipur City.

3.3 Analysis of Anaerobic digestion process for solid waste of Jaipur City

Only biodegradable waste takes part in anaerobic digestion. In this process waste is decomposed in absence of oxygen to produce Biogas which can be further used to obtain power also.

Table- 5 Biodegradability of Waste

Components	Mass of waste in Kg. (Dry)	Bio-degradable fraction	Mass of Bio-degradable Waste
Paper	5.2	0.5	2.6
Textile	1.8	0.5	0.9
Plastic	0.99	0	0
Food & Yard waste	12.81	0.82	10.5
Rubber	0.8	0	0
Wood	0.79	0.7	0.553
Total	**22.39**		**14.55**

Biodegradable percentage of dry combustible part of waste = (14.55 / 22.39) X 100

= **65%**

3.4 Computation of Formula For Solid Waste of Jaipur City:

Table- 6 Calculation of No. of Moles of Elements of Waste of City

Component	Mass without H_2O	Mass with H_2O	Mole without H_2O	Mole with H_2O
Carbon	10.99	10.99	0.915	0.915
Hydrogen	1.4362	4.83	1.436	4.83
Oxygen	8.225	35.425	0.513	2.21
Nitrogen	0.5052	0.5052	0.036	0.036
Sulpur	0.0644	0.0644	0.002	0.002

Table - 7 Normalization of Mole ratio

Component	Mole Ratio (Nitrogen = 1)		Mole Ratio (Sulfur = 1)	
	Without H_2O	With H_2O	Without H_2O	With H_2O
Carbon	25.41	25.41	457.5	457.5
Hydrogen	39.88	134.16	718	2415
Oxygen	14.25	61.38	256.5	1105
Nitrogen	1	1	18	18
Sulfur	0.05	0.05	1	1

(a) The chemical formula without Sulfur are:

(1) Without Water – $C_{25.41}H_{39.88}O_{14.25}N$

(2) With Water – $C_{25.41}H_{134.16}O_{61.38}N$

(b) The chemical formula with Sulfur:

(1) Without Water-$C_{457.5}H_{718}O_{256.5}N_{18}S$

(2) With Water- $C_{457.5}H_{2415}O_{1105}N_{18}S$

3.5 Estimation of Biogas Generation by Anaerobic Digestion of Solid Waste of Jaipur City

$$C_{25.41}H_{39.88}O_{14.25}N + 9.06\ H_2O \Rightarrow 13.75\ CH_4 + 11.65\ CO_2 + NH_3$$

573.8 gm 220 gm 512.6 gm

Only Biodegradable fraction (65%) of total waste can be digested to produce gases so total amount of waste needs to be taken to generate 220 gm of CH_4 and 512.6 gm of CO_2 will be –

Total amount of waste X 0.65 = 573.8

Total amount of waste = 882.76 gm

Weight of CH_4 = (220 / 882.76) X 22.39 = 5.57 Kg

Weight of CO_2 = (512.6 / 882.76) X 22.39 = 13 Kg

Density of CH_4 and CO_2 are taken as 0.7167 g/l and 1.9768 g/l respectively (Tchobanoglous etal)
Volume of CH_4 = (5.57 / 0.7167) = 7.77 m^3
Volume of CO_2 = (13 / 1.9768) = 7.77 m^3
Total volume of gas generated = 6.57 + 7.77 = 14.34 m^3
% of CH_4 = (7.77 / 14.34) X 100 = **54.18%**
% of CO_2 = 100 - 54.18 = **45.82 %**
Amount of gas generated per kg = 14.34 / 100 = **0.1434 m^3/Kg**

3.6 Calculation of Power Generation Potential of Waste by Anaerobic Digestion

Amount of waste generated in Jaipur City = 1383 X 10^3 Kg/day
Total amount of biogas generated = 1383 X 10^3 X 0.1434 = 198.32 X 10^3 m^3/day
Typical Digestion Efficiency (60%) = 198.32 X 10^3 X 0.6 = 118.92 X 10^3 m^3/day
Biogas Efficiency = 0.8 X fraction of waste digested
= 0.8 X 118.92 X 10^3 = 95.19 X 10^3 m^3/day
Net Calorific Value of Biogas = 5000 K Cal/m^3
Energy Recovery Potential (KWH) = 5000 X =95.19 X 10^3 X 1.16 X 10^{-3}
= 5.52 X 10^5
Power generation (KW) = (5.52 X 10^5) /24 = 2.3 X 10^4
Conversion efficiency = 30%
= 2.3 X 10^4 X 0.3 = 6901.53 KW
35 % amount will be lost as heat so net power generation per day
= (6901.53 X 0.65)/1000
= **4.48 MW**

The physical characteristics of solid waste of Jaipur city shows that there is high percentage of Biodegradable waste (42.7%) and Inert waste (45.2%). Moisture content of combustible fraction of waste found to be very high with 57.75% %. The Net Calorific Value is calculated by Dulong's formula as 1019 Kcal/Kg. Anaerobic Digestion is suggested as best treatment option for solid waste of Jaipur. The Biodegradable fraction of waste is calculated as 65% and Chemical formula of waste with and without Sulfur is computed to be $C_{457.5}H_{2415}O_{1105}N_{18}S$ and $C_{25.41}H_{134.16}O_{61.38}N$. The composition of Biogas generated from Anaerobic digestion of waste was 54.18% CH_4 and 45.82% CO_2.The total amount of Bio gas generated was found to be 0.1434 m^3/Kg that has potential to generate 4.48MW of Power per day.

4. CONCLUSION

From the analysis of results it was found that the properties of waste of Jaipur matches the characteristics of waste in developing countries. Now a days power generation from the waste is one of the best method for revenue generation. There are mainly two methods for energy recovery from waste namely Incineration and Anaerobic digestion. The Characteristics of waste of Jaipur shows that Anaerobic digestion should be preferred over Incineration. Apart from power generation some amount of compost also produces during anaerobic digestion. There are still lot of technological advancement is to be done in the field of anaerobic digestion, specially in developing and Asian countries. Thermophilic bacteria can be used instead of mesophillic bacteria which improve the quality of compost and High solid Anaerobic digestion can be used in place of low solid anaerobic digestion that increases the amount of methane generation and also reduces the amount of waste water discharged during the process. European countries like Germany and Denmark are leading in this field.

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