RECOVERY OF ELECTRIC ENERGY FROM MUNICIPAL SOLID WASTE OF JESSORE TOWN IN BANGLADESH

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ABSTRACT

Over the last half century, the energy crisis and environmental degradation has been considered as two major issues of growing concern for our global development. Municipal solid waste (MSW) has excessive negative consequences on environmental health. Furthermore, load shedding has become a great barrier in socio-economic growth of Bangladesh due to the serious crisis of electricity. This study also focused on energy recovery potential of MSW by converting it into electric energy. The organic solid waste encompasses a huge amount of energy and therefore, interest in renewable energy resources from these wastes has been increased, nowadays. Bangladesh as well as Jessore town faces a great environmental problems due to improper management of MSW. This study illustrated that the waste generation rate in Jessore town was found to be around 52.65 ton/day during the study period. Also, the heat energy and electric power generation prospects from the MSW were estimated as 13281.11 kJ/kg and 38230.19 kWh/day, respectively. Moreover, the recoverable electricity from MSW has been found as 1.60 MW that is about 20% of total demand in this area. This study recommended that proper waste management strategy as well as awareness rising regarding the management of MSW is prerequisite for the improvement of present status of human living.

Keywords: *Dulong's formula, energy recovery, Jessore town, municipal solid waste, waste management*

1. INTRODUCTION

Nowadays, Disposal of solid wastes has become a worldwide issue of growing concern and proper management of these wastes is always a challenging task especially for developing countries like Bangladesh. Bangladesh is a densely populated developing country in the world and the population will be about 17 Core by 2020 (BBS, 2001). With the rapid growth of population, Municipal Solid Waste (MSW) generation is increasing day by day which will create an incredible environmental hazard and social problem in city lives (Hasan & Chowdhury, 2006). At present, a large portion of the waste is dumped in unplanned sites and many of them are not properly managed that creates severe environmental hazards. One estimate shows that 5.2 million people (including 4 million children) die each year from waste-related diseases. Therefore, Proper waste management scheme is needed to ensure health and environmental safety. Furthermore, Load Shedding has been turned into a vital issue in our country. The electricity generation capacity of Bangladesh was approximately 4.7 GW in 2009 while, only 30% people of the population of Bangladesh has access to electricity. In Addition, frequent load shedding disrupts the whole uses (Meah *et al*., 2010). Numerous waste management tactics have been proposed and evaluated by several researchers. However, electric energy recovery concept from Municipal solid wastes is a new aspect regarding the proper utilization of MSW. A huge amount of waste produce every day in our country and most of the wastes are disposed only into land filling however; this research has been motivated to focus on the opportunity of electric energy generation from these MSW. At present the generation rate of solid wastes in Bangladesh is around 13332 ton in a day and it will be increased to 47000 ton in a day by 2025 (Chowdhury, 2008). The organic solid waste encompasses a huge amount of energy and therefore, interest in renewable energy resources from these wastes has been increased, nowadays. Jessore town is the heart of southern Bengal and an important area of Bangladesh. Hence, this study has been intended to evaluate the present status of MSW management as well as the characterization and composition of MSW of Jessore town. Also, the scope of electric energy recovery from the MSW has been demonstrated in theoretical approach.

2. STUDY AREA

Jessore, the present study area, the first district of undivided Bengal which is an expanding centre of south-western Bangladesh. It is a major industrial and commercial centre stands on the bank of the river Bhairob. Jessore district is currently covers an area of 2578.20 sq. km in which Jessore town covers an area of 25.72 sq.

km. and the population of the district was about 2,440,693 in 2012 estimation. In fact Jessore town has a population (1,178,273) almost half of that of the entire district (Bangladesh Bureau of statistics, 2012). The district lies between 22º 48' and 23º 22' north latitudes and between 88º 51' and 89º 34' east longitudes. Jessore town faces a great environmental problem due to improper management of MSW (Hossain *et al.*, 2014).All the waste of Jessore town are dumped in two selected areas of Hamidpur and Jhumjhumpur.

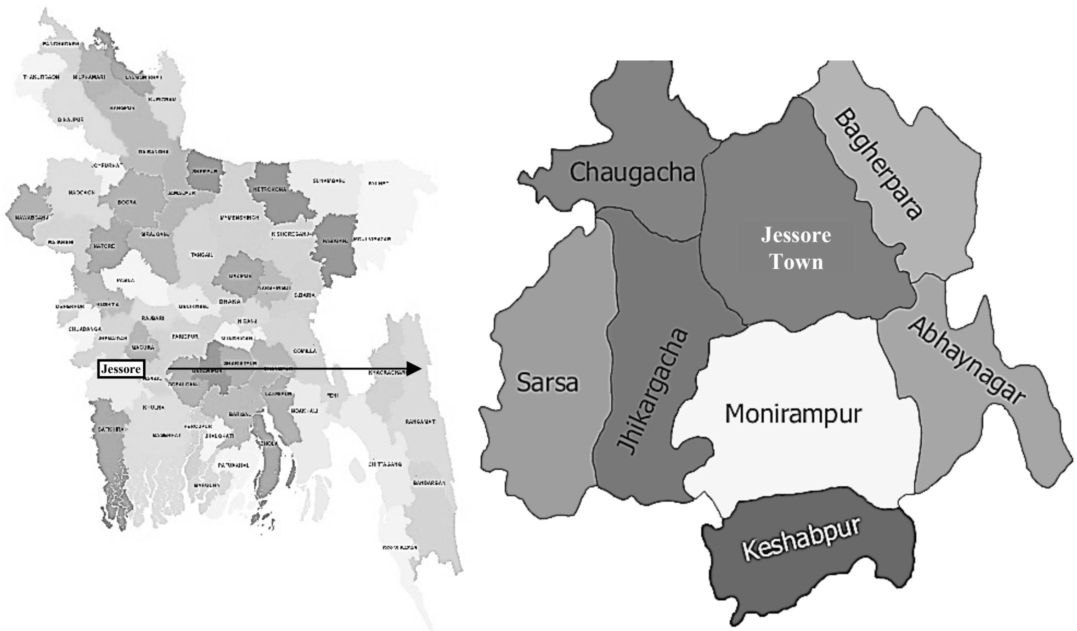

Figure 1: Study Area (Jessore Town)

3. MATERIALS AND METHODS

Both primary and secondary data have been used in conducting the study. Primary data collection includes the field observation and collection of MSW sample as well as exhaustive interviews of respondents groups like corresponding employees and garbage collectors. Their opinions were recorded as an evidence of existing waste management system in this area.

Figure 2: Data Collection and Present Scenario of Waste Deposal in Jessore Town

Secondary data has been assembled through pursuing different reports relevant to Jessore town, web materials, various articles, journals and books. Also, Various NGOs and organization are visited regarding the collection of secondary data. The Field observation and present scenarios of waste disposal in Jessore town are depicted in figure 2. For the collection of MSW sample, a variety of waste characterization methods can be used (USEPA, 1996). A simple method of sampling for the characterization of MSW is sampling directly from waste generation sources, which have been applied in this study. Waste Collection was performed from a number of waste generation sources such as residential, commercial, institutional and open areas (as street sweeping). Then the samples were transported to Khulna University of Engineering & Technology (KUET) for laboratory testing of moisture content in the various types of waste. Finally, theoretical analysis was executed and some proposal had been initiated. The details study outlines are shown in figure 3.

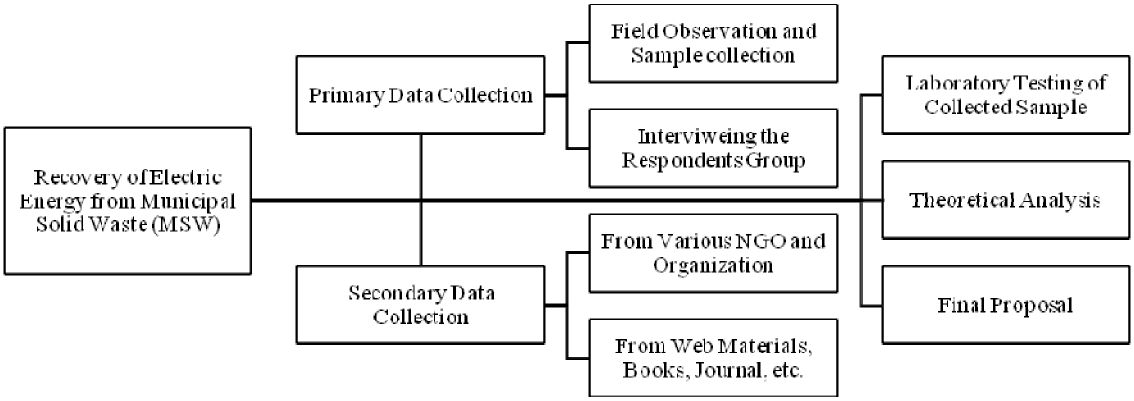

Figure 3: Study Outline

3.1 Determination of Moisture Content

After segregation of waste, all the wastes are weighted separately and collected data before drying of the sample. All the samples were reserved into an oven with 105°C temperature for 3 hours after weighted. The oven was maintained with 150°C temperature for first one hour. Then, the elements were weighted and again kept into the oven with same temperature. This process was done several times before reaching in a fixed weight of the elements. After drying, all the elements of household wastes were kept into the desiccators for reaching room temperature and finally, dry wet were taken. Then the Moisture content (W %) were calculated by the following equation (Yusuff *et al.*, 2014) :

$$\text{Moisture Content} = \frac{a-b}{a} x100 \quad (1)$$

Where, a = the weight before drying; b = the weight after drying

3.2 Heat Energy Content (HEC)

Heat Energy content can be obtained from the wet mass and dry mass of the household waste. The total amount of energy can be calculated by using Dulong equation (3) and chemical composition of household waste such as Carbon (C), Hydrogen (H), Oxygen (O), and Sulphur (S). Modified Dulong equation can be written as:

$$\text{Heat Energy Content } E,\ \frac{KJ}{KG} = 337C + 1428\left(H - \frac{1}{8}O\right) + 9S \quad (2)$$

The Heat energy can be calculated by using the Dulong equation, considering Nitrogen in the formula as below:

$$\text{Heat Energy Content } E,\ \frac{KJ}{KG} = 337C + 1428\left(H - \frac{1}{8}O\right) + 93S + 23N \quad (3)$$

Where, C = Carbon (%), H = Hydrogen (%), O = Oxygen (%), S = Sulphur (%), N = Nitrogen (%)

3.3 Electric Power Generation (EPG)

Various steps were followed to calculate electric energy form MSW. Firstly, the generated heat energy was used to calculate steam energy which is 70% of heat energy. Finally net electric power generated by solid waste was calculated by accounting station service allowance and heat losses (Rathi & Kumar, 2014). The steam energy is used to run the turbines; these turbines are coupled with generators which produces electricity. Heat rate is the heat input required to produce one unit of electricity (kWh).

$$1\ kW = 3,600\ kJ/h \quad (4)$$

From the above equation it is interpreted that if the energy conversion is 100 % efficient, 3600 kJ energy is required to produce one unit of electricity. But practically no energy conversion is 100% efficient and therefore, considering the conversion efficiency of 31.6% in a power plant, heat input of 3600 ÷ 31.6% = 11395 kJ/kWh is required. Hence, to produce 1kWh electrical energy 11395 kJ of steam energy is required.

$$\text{Electric Power Generation rate per Kg, } P = \frac{Stream\ Energy}{11395\ kJ/kWh} = \frac{70\%\ of\ Heat\ Energy}{11395\ kJ/kWh} \quad (5)$$

$$\text{Total Electric Power Generation per day, } P_{total} = P \times Total\ Waste\ Generation\ per\ day \quad (6)$$

Station service allowance, S_A= *6% of electric power generation* (7)

Unaccounted heat loss, H_L= *5% of electric power generation* (8)

Net electric power generation, $P_{Net}= P_{Total} – (S_A+H_L)$ (9)

The above generated electricity is for one day and one day has 24 hours, so using this net electric power is calculated for per hour basis.

Final electric power generated, $P_{Final} = \frac{P_{Net}}{24\ h} MW$ (10)

4. RESULTS AND DISCUSSION

The Main goal of the paper is initialised to calculate total electric power generation from MSW. Therefore, waste generation rate per day and percentage composition of various waste components are the two most important types of data for decision makers (Cheng and Hu, 2010). This information is necessary in order to identify waste components for finding resource of energy and recycling programs (Staley & Barlaz, 2009).

4.1 Waste Generation in Jessore Town on the Basis of Sources

This study illustrated that the waste generation rate in Jessore town was found to be around 52.65 ton/day during the study period. Most of the waste generated in this area is domestic waste and the rate of domestic waste generation is around 35.65 ton in a day. Also the commercial, industrial and clinical wastes were found to be around 6.43 ton, 2.57 and 0.54 ton in a day, respectively. The collected waste from street sweeping was around 3.59 ton in a day. The amounts of waste generation from different sources in Jessore town per day are shown in figure. Most of the information was collected from different secondary sources as Journal, website and various NGOs relevant to the waste management system of Jessore Town as well as the whole country.

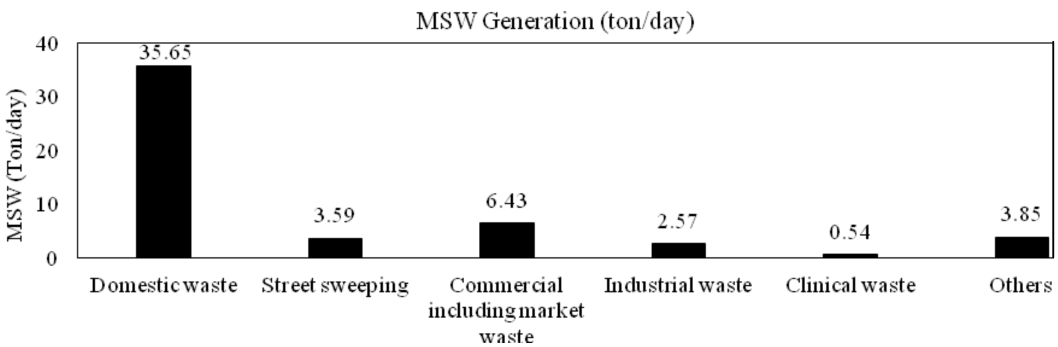

Figure 4: Waste generation in Jessore Town

4.2 Waste Components

In urban Bangladesh, solid wastes are originated from residential houses, street sweeping, commercial, industrial and other sources includes dust, ash, vegetable and animal bones, paper and packing of all kinds, rags and other torn fabrics, garment materials and many other trash (Alam & Sohel, 2008).

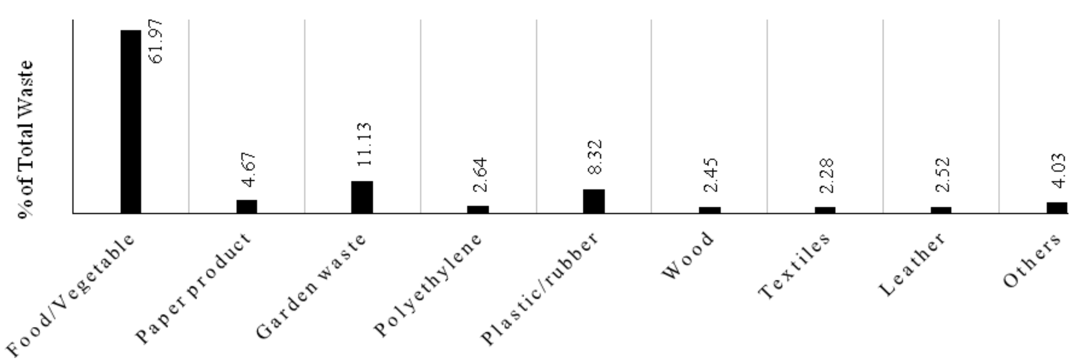

Figure 5: Organic Waste Component in Percentage

Our observation illustrated the overall quantity of a number of organic compounds in the solid waste of Jessore town. On average, 61.97% of total MSW were found to be domestic, 4.67% paper product, 11.13% garden waste, 2.64% polyethylene, 8.32% plastic or rubber, 2.45% wood, 2.28% textiles, 2.52% leather and 4.03% were categorized as others. Most of the waste of Jessore town is domestic waste and these waste were found to be dumped in Hamidpur and Jhumjhumpur area of the town. Organic waste component in percentage with respect to total waste generation is shown in figure 5.

4.3 Wet Mass and Moisture Content of MSW

From the laboratory test and analysis, the percentages of moisture content were found in the solid waste of Jessore town. The maximum moisture content was found to be as 17.62 ton/day for food/vegetable waste that is around 54% of its wet mass. Again, further significant moisture content was found in garden waste, wood and textiles while other types of wastes contain negligible amount of moisture content as shown in the table below. The minimum moisture content was found to be as 2% for plastic or rubber waste.

Table 1: Average Composition for Solid Waste for Jessore Town

Organic Waste Component	Wet Mass (ton/day)	Moisture Content (%)	Moisture Content (ton/day)
Food/Vegetable waste	32.63	54	17.62
Paper product	2.46	7	0.17
Garden waste	5.86	43	2.52
Polyethylene	1.39	4	0.06
Plastic/Rubber	4.38	2	0.09
Wood	1.29	12	0.15
Textiles	1.20	14	0.17
Leather	1.33	7	0.09
Others	2.12	4	0.08
Total	52.65		20.95

4.4 Dry and Wet Mass comparison of MSW

The variation between dry and wet mass of MSW is shown in figure 6 below. The maximum variation was found in food/vegetable waste due to high moisture content. The wet mass of food/vegetable waste was found as 32.63 while the dry mass was found to be 15.01 ton/day. The wet and dry mass were found to be 2.46 and 2.29 for paper product, 5.86 and 3.34 for garden waste, 1.39 and 1.33 for Polyethylene, 4.38 and 4.29 for plastic/rubber, 1.29 and 1.14 for wood, 1.203 and 1.03 for textiles, 1.33and 1.23 for leather as well as 2.12 and 2.04 for other waste, respectively.

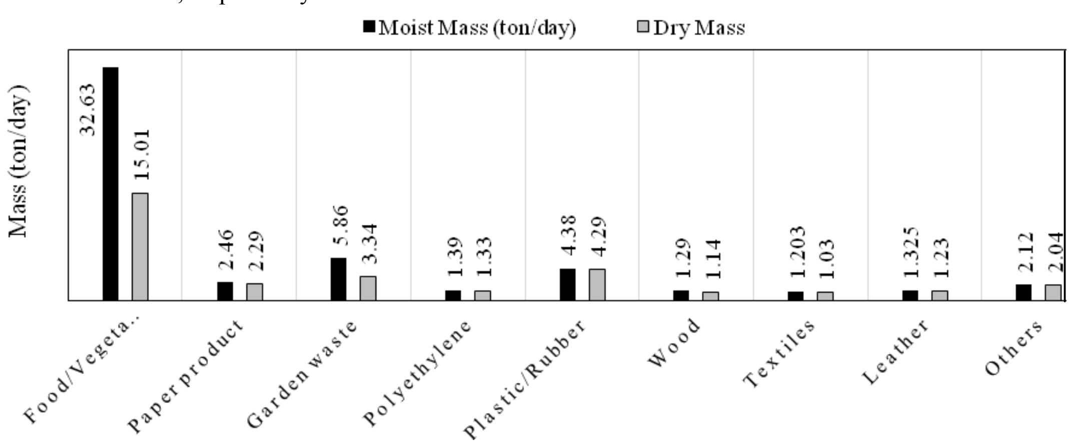

Figure 6: Dry and Wet mass comparison of MSW

4.5 Analysis of Electricity Generation

The percentages of chemical components i.e. carbon, hydrogen oxygen, nitrogen and sulphur in different constituents of the waste are shown in table 2. For the analysis of electricity generation Dulong's formula was used. The principal products of anaerobic decomposition are methane and carbon dioxide; ammonia, hydrogen sulphide and mercaptans (sulfonated hydrocarbons) are also generated (Themelis and Kim, 2002).

Table 2: Percentage of the Chemical Component of Different Types of Waste

Waste component	% weight				
	Carbon	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulphur**
Food/Vegetable waste	46.5	7.3	39.8	2.4	0.1
Paper product	43.5	6	44	0.3	0.2
Garden waste	44.2	5.4	45.6	2.6	0.2
Polyethylene	80.5	14.3	3.2	2	-
Plastic/Rubber	60	7.2	22.8	-	-
Wood	49	6	42.7	0.2	0.1
Textiles	55	6.6	31.2	4.6	0.2
Leather	69	9	5.8	6	0.2
Others	26.3	3	2	0.5	0.2

The percentage of chemical component as describe in table 3 were used for determining the approximate chemical formula for dry combustibles and percentage composition of carbon, hydrogen, oxygen, nitrogen and sulphur. Chemical compositions of waste fraction are calculated based on the corresponding dry mass of the waste type.

Table 3: Chemical Composition of Waste Fraction in Jessore Town

Waste component	Moisture Content (ton/day)	Dry Mass (ton/day)	Mass (ton/day)				
			Carbon	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulfur**
Food/Vegetable waste	17.62	15.01	6.980	1.096	5.974	0.360	0.015
Paper product	0.17	2.29	0.996	0.137	1.008	0.007	0.005
Garden waste	2.52	3.34	1.476	0.180	1.523	0.087	0.007
Polyethylene	0.06	1.33	1.071	0.190	0.043	0.027	0.000
Plastic/Rubber	0.09	4.29	2.574	0.309	0.978	0.000	0.000
Wood	0.15	1.14	0.559	0.068	0.487	0.002	0.001
Textiles	0.17	1.03	0.567	0.068	0.321	0.047	0.002
Leather	0.09	1.23	0.849	0.111	0.071	0.074	0.002
Others	0.08	2.04	0.537	0.061	0.041	0.010	0.004
Total	20.95	31.70	15.607	2.221	10.446	0.614	0.036

The total value of carbon, Hydrogen, Oxygen, Nitrogen and Sulphur were found from the summation of corresponding values of various types of waste. Then, the moisture content was separated into Hydrogen and Oxygen and added it to the previous value of Hydrogen and Oxygen as shown below. The percentages of the chemical components were computed based on the value of total chemical composition. Finally number of K. moles and M. moles were computed by the atomic mass of the corresponding chemical component.

Hydrogen: (2/18) 20.95 ton = 2.328 ton
Oxygen: (16/18) 20.95 ton = 18.622 ton

Table 4: Chemical Formula Deduction for MSW of Jessore Town

Chemical Component	C	H	O	N	S
Total Composition	15.607	4.549	29.068	0.614	0.036
% Composition	31.29	9.12	58.28	1.23	0.07
Atomic Weight (Kg/Kmol)	12.01	1.01	16	14.01	32.07
No of K. Moles	1300	4504	1817	44	1
No of M Moles /day	1.3	4.5	1.82	$0.044 \approx 0$	$0.001 \approx 0$

Now the chemical formula for MSW of Jessore Town can be written as: $C_{1300}H_{4504}O_{1817}N_{44}S$ *or* $C_{1.3}H_{4.5}O_{1.82}$

The energy conversion can be performed across two step of energy flow. Firstly the heat energy is produced from the Municipal Solid Waste. The heat released from combustion of solid wastes was partly stored in the combustion products (gases and ash) and partly transferred by convection, conduction, and radiation to the incinerator walls and to incoming waste. Thereafter, the heat energy can be converted into electric energy by the process as shown in figure below.

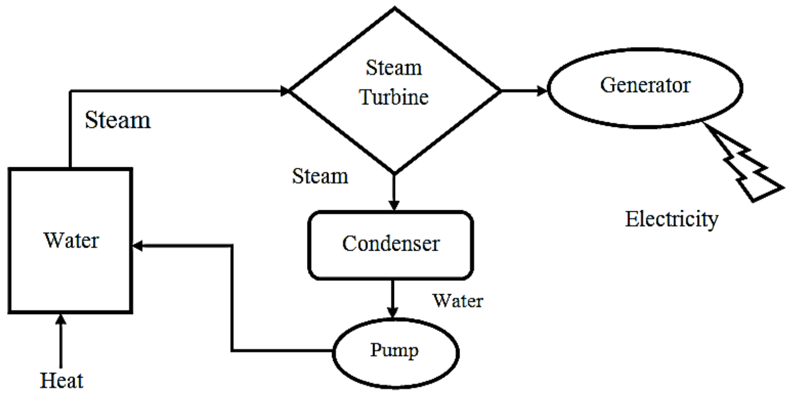

Figure 7: Process flow diagram for heat energy to electric energy conversion

The energy content of the waste can be estimated using the modified Dulong's Equation or the heating value of individual waste components. The estimation of electric energy is described in the table below.

Table 5: Estimation of Electric Energy

Term	Formula	Value
Heat Energy Content	E, $\frac{KJ}{KG}$=337C+1428$\left(H - \frac{1}{8}O\right)$+93S+23 N	13281.11 KJ/Kg
Steam energy available	70 % of heat energy	9297.78 KJ/kg
Electric Power Generation rate per Kg	$P=\frac{StreamEnergy}{11395\ KJ/kWh}$	0.81586459kWh/Kg
Total Electric Power Generation per day	P_{total}=P × Total Waste Generation per day	42955.27 kWh
Station service allowance and Unaccounted heat loss	S_A+H_L= 11% of electric power generation	4725.08 kWh
Net electric power generation per day	$P_{Net}= P_{Total} - (S_A+H_L)$	38.23 MWh
Final electric power generation	, $P_{Final} = \frac{P_{Net}}{24\ h}$	1.60 MW

On average 8 MW electricity is required for Jessore town (BPDP, 2007) and the recoverable electricity from MSW has been found as 1.60 MW that is about 20% of total demand in this area. Moreover, the produced electricity may be an option to fulfil the electricity demand of any University area like Jessore University of Science & Technology or any residential area.

4.6 Benefit Analysis

From the analysis of different studies it is found that the price for producing per unit electricity from municipal solid waste by incineration would be between taka 9.50-10.50 (USD 0.136-0.150/unit). Where in Bangladesh, the electricity production cost for each unit of electricity from wind based power plant could be around taka 10.00-12.00 (USD 0.142-0.171/unit), from diesel fired power plants is taka 8.00-14.00 (USD 0.114- 0.200/unit) and Taka 8.00 (USD 0.114/unit) from furnace fired power units (Rouf, 2011).

Municipal Solid Waste (MSW) contains organic as well as inorganic matter. The latent energy present in its organic fraction can be recovered for profitable utilization through adoption of suitable Waste Processing and Treatment Technologies. The recovery of energy from wastes also offers other benefits as follows (Rouf, 2011):

a) The total quantity of waste gets reduced by nearly 60% to over 90% depending upon the waste composition and the adopted technology

b) Demand for land, which is already scarce in cities for land filling is reduced
c) The cost of transportation of waste to far-away landfill sites also gets reduced proportionately; and
d) Net reduction in environmental pollution.

It is, therefore, only logical that, while every effort should be made in the first place to minimize generation of waste materials and to recycle and reuse them to the extent feasible, the option of Energy Recovery from Wastes be also duly considered.

5. CONCLUSIONS

Management of Waste is a challenging task in the modern age also an obligatory aspect for standard living. Jessore town is an earliest town and this area produces large quantity of waste. Most of the component of waste is food or vegetable waste which is already being used to produce organic fertilizer. Waste to Energy (WTE) solves the problem of MSW disposal while recovering the energy from the waste materials with the significant benefits of environmental quality, increasingly accepted as a clean source of energy. WTE incineration needs to be implemented to make greater contribution in supplying renewable energy in Bangladesh, while helping solving the country's MSW management problem in the coming decade. The challenge of MSW disposal and the demand for alternative energy resources are common in developing countries. It is expected that the experience on the development of WTE in Bangladesh can offer some helpful lessons to other developing counties. At present in Bangladesh, the electricity production from MSW is done by incinerator process. This research works suggested that more electric energy can be extracted from waste by adopting gas collection procedure. Per unit cost of generation of electric energy from waste are less than others. As, organic waste and moisture is most important than others, the traditional system of waste generation will be improved. Therefore municipal solid waste could be used as an alternative source of energy. This study clarified that the waste generation rate in Jessore town was found to be around 52.65 ton/day during the study period. Also, the heat energy and electric power generation prospects from the MSW were estimated as 13281.11 kJ/kg and 38230.19 kWh/day, respectively. Moreover, on average 8 MW electricity is required for Jessore town and the recoverable electricity from MSW has been found as 1.60 MW that is about 20% of total demand in this area. This study recommended that proper waste management strategy as well as awareness rising regarding the management of MSW is prerequisite for the improvement of present status of human living. A needful decision should be taken by the Jessore town authority as well as the Government of Bangladesh to implement Waste to energy (WTE) production project as an alternative option of power generation to meet the electricity scarcity of the country. A consultative meeting should be held with environmentalist, healthcare service providers, waste handlers, and municipal authorities to select appropriate place and technology of producing energy from MSW. Solid waste to energy production technology should also be considered as pollution diminution as well as greenhouse gases reduction tools in making decision on implementing of waste-energy production project.

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