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STUDY OF SOLID WASTE MANAGEMENT OF RCC AND THE POTENTIALS OF ENERGY RECOVERIES FROM THE SOLID WASTES

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Abstract- *This report presents a study of systems of solid waste generation, collection capacity, and determination of characteristics and compositions of solid wastes and different techniques of electricity generation from the solid wastes generated in Rajshahi City Corporation (RCC) areas, Bangladesh. Study shows that the solid wastes of RCC contain suitable energy recoverable materials as well as other solid materials, such as, glass, metal, dangerous waste materials from hospital and industries. Present waste management of RCC is found to be inappropriate for energy extraction and needs modification. Consumer awareness as well as incorporation of necessary policy is very essential in order to separate and collect energy extractable and non-extractable materials from the sold wastes to maximize electricity production output from a proposed waste-to-electricity power plant. A simple calculation shows considerable potentials of energy recovery from the wastes. Among the different techniques for electricity production discussed here are incineration, pyrolysis, anaerobic digestion (AD) and landfill gas recovery. Techniques are compared with some set key parameters appropriate for Bangladesh's perspectives.*

Keywords: Municipal solid waste, Management, Energy extraction, Electricity production

1. INTRODUCTION

Energy is the basic ingredient of the process of economic development and the driving force of the global economy. A developing country like Bangladesh needs progressively increasing amount of energy for its growing economy and population. However, it has limited energy resources that can be employed for these increasing energy demands. Hence, search for alternative energy sources is vital and on the other hand it has environmental benefits.

Wastes are unwanted or unusable materials that emanate from numerous sources from industry and agriculture as well as businesses and households and can be liquid, solid or gaseous in nature, and hazardous or non-hazardous depending on its location and concentration [1]. They are usually generated from human activities. The term municipal solid wastes (MSW) considered in this study are synonymously used for urban solid wastes and correspond to the solid waste generated from urban sources mentioned above.

The source classification of urban solid waste is based on the fact that waste emanates from different sectors of society such as residential, commercial and industrial sources. A good example of the source classification was provided by the World Bank [2] in a study in Asia, which identified the sources of waste as residential, commercial, industrial, municipal services, construction and demolition, processing and agricultural sources. MSW can be categorized as biodegradable and non-biodegradable wastes and also as hazardous and non-hazardous wastes [3]. Hazardous wastes are generated from hospitals and clinics and from industries.

The indiscriminate disposal of solid waste in public places causes serious environmental hazards and health risks. However, useful conversion of these solid waste-to-energy can contribute considerably to resolve the problems. Solid wastes have already been treated as alternative energy sources around the world. Depending on the nature of solid wastes, they can be useful to extract energy from them. However, in order to utilize these wastes as alternative sources of energy, enough data bank on MSW is essential. In most developing countries, even the most basic data on wastes such as the quantities generated and composition of the waste stream are lacking, making it difficult to organize waste management effectively [4].

Solid waste management is the most intractable problems of urban centers. Gbekor [5] has referred to waste management as involving "the collection, transport, treatment and disposal of waste including after care of disposal sites". The total services require a considerable proportion of municipal effort, budget and workforce. Deficiencies in the management of solid wastes are very pronounced in cities and towns of developing countries like Bangladesh. The existing literature shows the inadequacy in data and its analysis of MSW under RCC. This objectives of the present study include study of existing solid waste management system of RCC; analysis of the physical and chemical characteristics of solid wastes; study and analysis of different techniques for recovering energy from solid wastes and approx. estimation of potentials of energy extraction from solid wastes under RCC.

2. OVERVIEW OF SOLID WASTE MANAGEMENT SYSTEM OF RCC

According to available statistics, about 16,380 tons of wastes are produced in Bangladesh per day [6]. Based on the total population of the Dhaka, Chittagong, Rajshahi and Khulna city corporations and average waste generation per capita of 0.5 kg/day, a total of 8300 tons waste are generated daily [7]. The average recovery rate of MSW is 70% [8]; i.e., 2.12 million tons (mton) per year.

Around 0.7 million people live in RCC area (92.93 km^2). They produce about 400 metric ton wastes/day. The responsibility of the Conservancy Division of RCC is to dispose off and manage these wastes including the medical wastes. Among the 30 wards under RCC, fifteen wards are covered by 'door to door waste collection' facilities. There are 22 secondary collection points and one dumping site (3.5 feet deep in ~17 acres area). Among the different collection points, hospitals, railway station, and Shaheb Bazaar are covered by RCC collection system. About 280 metric ton/day wastes are collected and disposed off in the waste disposal area. Out of that about 120 metric ton/day are collected by the farmers for making of compost for agricultural lands. Figure 1 presents the trend in solid waste generation from year to year in RCC area [9].

Primary collection refers to the system through which mainly the household wastes are collected from door to door to transfer them into secondary waste disposal point by hand-trolleys or vans.

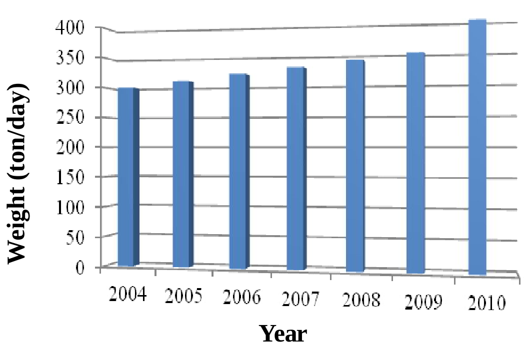

Fig.1: Waste generation per year (ton/day) in RCC [9]

Residents are responsible for bringing their waste to RCC's waste collection points where dustbins/containers are located. The regulation is clear where dustbins/containers are located. On the contrary, it is unclear where no dustbins/containers are provided.

Wastes, which are, dropped into the primary disposal points, are carried to the secondary collection points by vans. For the secondary collection system, about 213 vans are employed to carry these wastes to 22 secondary waste disposal points in the RCC area.

Wastes are finally transported from secondary point to the final waste disposal point by trucks and tractors. About 12 tractors/trucks are employed in order to transport these wastes, to the final disposal point. Final disposal point is located in Terokhadia, Rajshahi.

2.1 MSW Management Organizations [9]

The total management system comprises of a few departments to conduct all the relevant activities associated with the system.

(a) **Conservancy department**

Conservancy department is the core organization for solid waste management. It undertakes street and drain cleaning, loading and unloading of wastes at places of dustbins/containers and disposal sites. Conservancy department consists mostly of field workers and very few officers at headquarters.

(b) **Transport department**

Transport department has two parts: central pool and conservancy pool. The conservancy pool is in charge of transportation of waste from dustbins/containers to disposal sites.

(c) **Engineering department**

Engineering department is involved in solid waste management for operating heavy equipment at disposal sites and repair of vehicles and heavy equipment used. Mechanical division repairs transport vehicles and heavy equipment and also are in charge of manufacturing steel containers as per demands of the Conservancy department. Civil Engineering division is also involved in the field of facility construction and site development for waste disposal.

(d) **Store and purchase department**

Store and Purchase department procures conservancy appliances, such as brooms and baskets; at the request of the conservancy dept. Store and purchase department also purchases spare parts for vehicles and equipment.

3. CHARACTERISTICS OF SOLID WASTES GENERATED IN RCC

Characterization of MSW is important to evaluate its possible environmental impacts on nature as well as on society. Physical characterization of solid wastes and their, proximate analysis and chemical characterization are done in this study. These analyses indicate the compositional suitability of MSW for energy extraction. The characteristics are directly influenced by the local aspects such as food habits, culture, socio-economic, seasonal, and climatic conditions.

3.1 Physical Characteristics

Physical characterization of the solid wastes of RCC are done by considering two parameters:

- Composition of solid waste
- Density

Composition of solid wastes

Solid waste consists of the highly heterogeneous mass of discarded materials such as plastic, polythene, wood, cloth, rubber, bricks, glass and others. The constituents are determined from point to point in Rajshahi city. We took 15 kg of sample and separated different components and identified various constituents. The quantity of the constituents was determined by weight in the taken sample. Sampling is done for 20 days at various locations in RCC area such as Central Jail gate, Helanabad, Kadirgonj, Terokhadia Railway station, Fire Service point, Motpukur, RUET gate, Sopura, Vodra, Talaimari and Shaheb Bazaar. Figures 2-4 shows the variation in constituents in the sample of solid wastes collected from different points in the city. Average values are presented in these figures while the sources can be classified as residential, commercial and industrial respectively. It can be observed in the figures that the major constituent is food waste in all the samples investigated in this study. Table 1 presents the estimation of combustible materials (such as food waste, cloth, etc.); non-combustible materials (such as brick, glass etc.) and recyclable materials (such as plastic, polythene, plastic, rubber and metal) in the solid waste samples collected from different sources. Here it is observed that the major part is combustible materials followed by the recyclable and the non-combustible materials. Therefore, the physical compositional analysis shows that these solid waste samples have high proportions of energy extractable materials.

Density

Typical density for various wastes is determined from the weight of the sample (kg) dividing by the volume of the sample collected.

$$\text{Density} = \frac{\text{Weight of sample}}{\text{Volume of sample}} \ (\text{kg/m}^3) \quad (1)$$

The average value of combustible solid waste is estimated as 400 kg/m^3. Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low-density wastes, on the other hand, indicate a high proportion of paper, plastics and other combustibles.

3.2 Proximate Analysis

Proximate analysis gives information about feedstock suitability in terms of moisture content, volatile matter content and fixed carbon content. In this study, however, only the moisture content is estimated in the collected samples. Moisture content is important in determining drying cost and energy content of the feedstock. Higher moisture content also presents immediate problem to all thermal processes since more energy is needed to evaporate the water. The moisture content in the feedstock would also reduce the calorific value of the feedstock.

In order to estimate the moisture content, 15 kg of sample was taken and weighted before and after drying

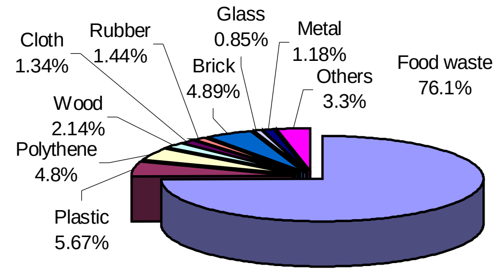

Fig.2: Average values of the constituents observed in the sample collected from residential source.

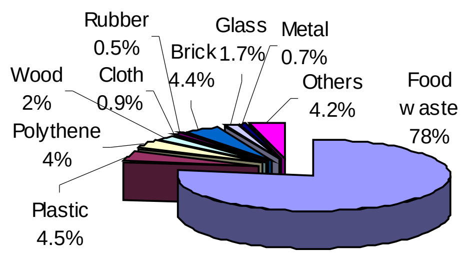

Fig.3: Average values of the constituents observed in the sample collected from commercial source.

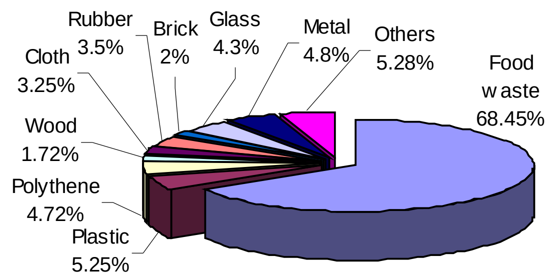

Fig.4: Average values of the constituents observed in the sample collected from industrial source.

Table 1: Compositional analysis of solid wastes in terms of combustible, non-combustible and recyclable materials.

Solid waste source	Combustible (%)	Non-Combustible (%)	Recyclable (%)
Residential	82.92	4.67	13.10
Commercial	85.27	6.07	8.66
Industrial	78.70	6.34	14.96

for seven days. The percentage of moisture content of solid waste samples taken at different point around the city is shown in the histogram in Figure 5. The moisture content varied from 40 to 75% in this study. High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions.

3.3 Chemical Characterization of Solid Waste

3.3.1 Elemental analysis

Chemical compositions of the solid wastes are identified by the determination of elemental contents in the sample such as Carbon, Nitrogen, Sulfur and Hydrogen. Dried sample was taken carefully to Bangladesh Council of Scientific and Industrial Research

(BCSIR), Dhaka for the purpose and Table 2 presents the data obtained from the solid waste sample (food waste) by them. The result indicates that the major elements are Carbon and Oxygen.

3.3.2 Determination of calorific value

The calorific value of solid waste is determined by using a bomb calorimeter. A bomb calorimeter measures the heat created by a fuel sample burned under an oxygen atmosphere in a closed vessel, which is surrounded by water, under controlled conditions. A dried combustible sample was taken into the bomb and the calorific value was determined by using the following formulae:

$$\text{Calorific value}=(m_w+m_e)*c_w(t_2-t_1)/m_f \quad (2)$$

Where

m_w=mass of water filled in the calorimeter in kg
m_e=water equivalent of apparatus in kg
c_w=specific heat of water in KJ/kgK
m_f=mass of sample in kg
t_1=initial temperature of water and apparatus in ^{0}C
t_2=final temperature of water and apparatus in ^{0}C

Three samples were tested and the calorific values were found to be varied from 20 to 25 MJ/kg. The values are compareable with the typical values of biomass fuels.

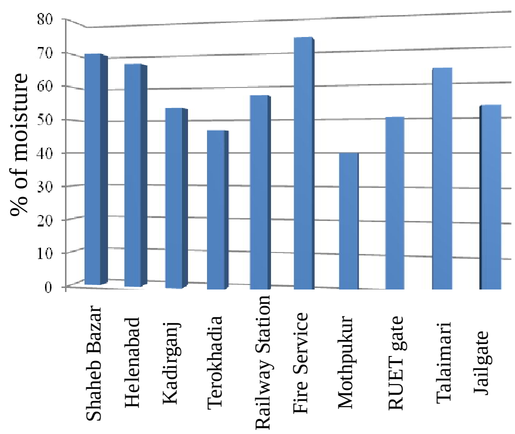

Fig.5: Moisture content of solid waste at different collection points.

Table 2: Elemental analysis of combustible solid waste

Elements	% by weight
Carbon	26.34
Nitrogen	1.90
Sulpher	0.03
Hydrogen	3.01
Oxygen and ash and other	68.72

4. POSSIBLE ENERGY RECOVERY FROM SOLID WASTES IN RCC

The potentials of energy have been calculated from their calorific value. We have taken the average value of the calorific values obtained for the combustible solid wastes for the energy recovery calculation.

The daily waste generation in RCC is about 400 ton/day. So the total waste generation in a year is about 146000 ton/year.

If the average rate of recovery of the MSW is considered as about 70%, and the considering the moisture content (about 40%) the total amount of available wastes

= 146000*0.7*0.5 = 61320 ton/year.

If the content of combustible materials in MSW is considered as about 80% (according to Table 1), the net amount of solid waste available will be

= 102200*0.8 = 49056 ton/year.

If the calorific value of solid waste is taken as 22.512 MJ/kg or 22512MJ/ton, the heat energy can be calculated as

= 49056*22512 (MJ/year)

Now if the conversion efficiency of heat energy to useful mechanical work is considered as about 30%, electrical power output per year with an alternator efficiency of 95%,

= (49056*22512*0.3*0.95)/(365*24*3600)
= **9.98** MW.

5. SOLID WASTE TO ENERGY CONVERSION TECHNIQUES

Energy can be recovered from the organic fraction of waste (biodegradable as well as non-biodegradable) basically through two methods [10]:

- Thermo-chemical conversion
    - Incineration
    - Pyrolysis/ Gasification
- Bio-chemical conversion
    - Anaerobic Digestion
    - Landfill Gas Recovery

5.1 Thermo-chemical Conversion

This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas. The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content.

Incineration [11]

It is the process of direct burning of wastes in the presence of excess air (oxygen) at temperatures of about 800^{0}C and above, liberating heat energy, inert gases and ash. Net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system (fixed bed/ fluidized bed) etc. In practice, about 65 to 80 % of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power via steam turbine-generators (with typical conversion efficiency of about 30%). While incineration is extensively used as an important method of waste disposal, it is associated with some polluting discharges which are of environmental concern; although in varying degrees of severity. These can fortunately be effectively controlled by installing suitable pollution control devices and by suitable furnace construction and control of the combustion process.

Pyrolysis/ Gasification

Pyrolysis is also referred to as destructive distillation or carbonization. It is the process of thermal decomposition of organic matter at high temperature (about 900^0C) in an inert (oxygen deficient) atmosphere or vacuum, producing a mixture of combustible carbon monoxide, methane, hydrogen, ethane and non-combustible carbon dioxide, water, nitrogen, gases, pyroligenous liquid, chemicals and charcoal. The pyroligenous liquid has high heat value and is a feasible substitute of industrial fuel oil. Amount of each end product depends on chemical composition of the organic matter and operating conditions.

Gasification involves thermal decomposition of organic matter at high temperatures in presence of limited amounts of air/oxygen, producing mainly a mixture of combustible and non-combustible gas (carbon monoxide, hydrogen and carbon dioxide). This process is similar to pyrolysis used., involving some secondary/ different high temperature (>1000^0C) chemistry which improves the heating value of gaseous output and increases the gaseous yield (mainly combustible gases $CO+H_2$) and lesser quantity of other residues. The gas can be cooled, cleaned and then utilized as alternative fuel in IC engines to generate electricity. [11, 12]

5.2 Bio-chemical Conversion

This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol. The bio-chemical conversion processes, on the other hand, are preferred for wastes having high percentage of organic bio-degradable matter and high level of moisture content, which aids microbial activity.

Anaerobic digestion (AD)

Anaerobic biodegradation of organic material proceeds in the absence of oxygen and the presence of anaerobic microorganisms. AD is the consequence of a series of metabolic interactions among various groups of microorganisms. It occurs in three stages, hydrolysis/ liquefaction, acidogenesis and methanogenesis. The first group of microorganism secretes enzymes, which hydrolyses polymeric materials to monomers such as glucose and amino acids. These are subsequently converted by second group i.e. acetogenic bacteria to higher volatile fatty acids, H_2 and acetic acid. Finally, the third group of bacteria, methanogenic, converts H_2, CO_2, and acetate, to CH_4. Generally the overall AD process can be divided into four stages: Pretreatment, waste digestion, gas recovery and residue treatment. The methane content in biogas can range from 45 to 80% by volume of the gas mixture [13]. Biogas can then be fed into gas engines or gas turbine engines to produce power. The detailed AD process is described in [10, 14].

Landfill gas recovery [15**]**

The waste deposited in a landfill gets subjected, over a period of time, to anaerobic conditions and its organic fraction gets slowly volatilized and decomposed according to the process similar to that taking place in an AD system as described earlier. This leads to production of landfill gas containing about 45-55% methane, which can be recovered through a network of gas collection pipes and utilized as a source of energy. Typically, production of landfill gas starts within a few months after disposal of the wastes and generally lasts for about ten years or even more depending upon mainly the composition of wastes and availability/distribution of moisture. The MSW generated in major Indian cities is rich in organic matter and has the potential to generate about 15-25 l/kg of gas per year over its operative period. A reasonable assumption for the gas collection efficiency for a properly planned gas collection system is 70 - 85%. Landfill gas can be used as a good source of energy, either for direct thermal applications or for power generation like biogas.

5.3 Advantages and disadvantages of different technological options

From the above discussion of waste-to-energy conversion technologies, relative merits and demerits one over other can be summarized in Table 4.

Table 4: Relative advantages and disadvantages of different energy recovery processes

Process	Advantages	Disadvantages
Incineration	- Most suitable for high CV waste, pathological wastes, etc. - Thermal energy recovery for direct heating or power generation. - Relatively noiseless and odorless. - Low land area requirement. - Can be located within city limits, reducing the cost of waste transportation.	- Least suitable for aqueous/high moisture content and low CV and chlorinated wastes. - Auxiliary fuel support may be required to sustain combustion. - Concern for emissions of toxic metals, particulates, SOx, NOx, chlorinated compounds. - High Capital costs. - Skilled personnel required. - Overall efficiency low
Pyrolysis/ Gasification	- Production of fuel gas/oil, which can be used for a variety of applications - Compared to incineration, control of atmospheric pollution can be dealt with in a superior way, in techno-economic sense.	- Net energy recovery may suffer in case of wastes with excessive moisture. - High viscosity of pyrolysis oil may be problematic for its transportation and burning.
Anaerobic Digestion	- Provides useful biogas fuel and high-grade soil conditioner. - No power requirement. Controls green house gases emissions. - Modular and cheaper construction of plant and closed treatment needs less land area. - Net positive environmental gains. - Can be done at small-scale.	- Unsuitable for wastes containing less organic matter - Requires waste segregation and heat addition for improving digestion efficiency.

Landfill Gas Recovery	- Least cost option. - Gas produced can be of similar quality of biogas obtained in AD. - Highly skilled personnel not necessary. - Natural resources are returned to soil and recycled. - Can convert low-lying marshy land to useful areas.	- Greatly polluted surface run-off during rainfall. - Soil/Groundwater aquifers may get contaminated by polluted leachate Inefficient gas recovery process can cause green house gas to escape to the atmosphere - Large land area requirement. - Spontaneous ignition/explosions.

6. RECOMMENDATIONS

These include recommendations for MSW management system of RCC and selecting suitable technology for energy recovery system.

- Waste separation is extremely important. Separation has to be done for biodegradable, non-biodegradable, recyclable, hazardous and non-hazardous items in separate bins. This has to be mandatory for every industry, institution and organization and clinic, hospital.
- Enough storage bins should be made available to the nearest distances to the respective sources.
- Wastes from meat and fish markets, fruits and vegetable markets, which are biodegradable in nature, should be collected separately and should be carried separately to the processing plants.
- Composting of solid wastes is very essential. RCC has a composting plan but this plant is stopped now. Generally the quality of compost is far better than common fertilizers for agricultural lands. So, the compost plant should run properly and management should develop a market for selling it at a cheaper price.
- At present RCC has no recycling plant. Recycling helps saving water, energy, and generates less contamination; it also reduces the amount of wastes to be collected, transported and disposed. So, the management should start a recycling plant immediately.

A number of essential parameters are compared among the available technologies, to choose the suitable technology for energy recovery from MSW. They are process technology (simple/complex), quality, quantity and availability of MSW, skills required, overall cost, space, impacts on lives and environment, conversion efficiency. After the comparison, it is recommended that the best technology for RCC MSW is landfill recovery and the next suitable one is AD system.

8. CONCLUSIONS

From this study the following conclusions can be made:

- Approximately 60% of total generated waste is collected by the management system of RCC. No separation of wastes and inadequate number of waste storage bins are observed.
- Compositions of MSW of RCC are found to be heterogeneous with about 70-80% biodegradable and about 81% of combustible and about 12% of recyclable wastes.
- Average moisture content of MSW is estimated as about 57%.
- Chemical compositions are identified as C-26.34%, N_2-1.9%, S-0.03%, H_2-3.01% and the rest is O_2, ash and others.
- The average CV of waste is estimated as 22.512MJ/kg, which can generate about 10MW electricity with a waste generation rate of 400 ton/year.
- Suitable technology for energy recovery from MSW of RCC can be landfill recovery or AD systems.

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