

Waste to Energy Technologies for Municipal Solid Waste Management in Bangladesh: A Comprehensive Review

Mohammad Zoynal Abedin and A. S. M. Luthful Karim



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ABSTRACT

Bangladesh has an impressive track record of development and has been among the fastest growing economies in the world over the past decade, supported by a demographic dividend, strong ready-made garment (RMG) exports, remittance, and stable macroeconomic conditions. With the growth of populace and the living standards, the goods and energy consumption in Bangladesh are seen to be increased which rises the waste generation. Thus, municipal waste management (MSW) and energy supply are becoming the great challenges for Bangladesh. Waste to energy (WTE) conversion technologies would be a very timely solution to an ever-growing problem. These technologies are environment-friendly and cost effective; however, these are not popular within the developing country Bangladesh. This paper discusses current waste status, significant progresses and future prospect of solid waste management process as well as evaluates the best possible WTE technology suitable for Bangladesh. It is found that Bangladesh produces approximately 13,332 tons of MSW per day in which almost 26% and 12% of total wastes are generated by its capital city, Dhaka and Chattogram, respectively. The incineration process for electricity production is seen to be the most effective WTE technology for Chattogram city. For instance, for one ton of MSW, the incineration process can provide 0.585 MWh electricity and 1.742 MWh heat with an emission factor of 0.28 ton of CO₂. With an average plant capacity cost of 2.1 USD which is lower than other WTE technologies. Therefore, the incineration can be utilized as the most effective WTE technology for major cities in Bangladesh.

Keywords: Municipal solid waste, Waste management, Waste to energy, Incineration, Electricity, Bangladesh.

1 INTRODUCTION

With the rapid progress of society, the demand of energy supply and waste management has increased rapidly. This trend will continue as people will strive to improve their living standards. Waste management so far has consisted of human excrements and sewage waste. With rapid urbanization, it is now considered as municipal solid waste (MSW), which includes other non-hazardous solid waste and other gaseous wastes consisting primarily of carbon dioxide, methane and others. Nations those are in lack of natural resources of energies are seen to take necessary attempts to generate energy from alternative sources, particularly from waste and biomass [1].

Bangladesh, the seventh most populated country in the world [2], is facing accelerated MSW generation with the increase of population and the rapid change of people's living standard [3]. The demand of domestic electricity in Bangladesh is more than the supply. Merely 42% of the population can access the electricity of national grid [4]. Therefore, the WTE conversion technologies could be used to lessen the overload of waste as well as to prevent the environment from pollution. The success of waste management is influenced by several factors like economic growth, urbanization, policy, governance, cultural and socioeconomic aspects, international influences, and institutional issues. Various types of live feedstock have been managed by using several well-known WTE technologies. For instances, pyrolysis is known for using plastics, gasification uses MSW, and anaerobic digestion uses bio wastes such as food and paper [5]. Among these, thermal processing of waste is an inviolable a part of each integrated WTE waste management system [6]. Though it has still very low contribution to countries' energy generation, it may be increased by enhancing the performances of the plant [7].

Generating sufficient electricity to meet the electricity demand and waste management are two of the most challenging factors in Bangladesh. Hence, various research has been conducted to manage both of them together. This paper discusses the initiatives taken in Bangladesh to meet these challenges in a way to propose a suitable WTE

Mohammad Zoynal Abedin ✉ and A S M Luthful Karim
Department of Mechanical Engineering
Dhaka University of Engineering & Technology
Gazipur 1707, Bangladesh
E-mail: abedin.mzoynal@duet.ac.bd

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technology. In these circumstances, the waste management system including present condition of waste management system and adverse effects of improper waste management system in Bangladesh is discussed in the following section.

2 WASTE MANAGEMENT IN BANGLADESH

Waste management can be described as the national control of various aspects of its life cycle such as waste collection, various techniques of disposal and assessment of the compositions. Effective waste management system plays a major role in controlling the adverse impact of wastes on the environment as well as human health within a country. The projected rate of growth of urban population in Bangladesh from 2010 to 2015 was almost 3% [8]. With the population growth, problems of waste management are also increasing in the major cities of Bangladesh. Dhaka, a rapidly developing metropolitan city, has a major concern regarding MSW management [9]. At present, there is hardly any technological advancement in terms of waste management that has been introduced so far in Bangladesh.

2.1 Present Condition of Waste Management

There are total 514 urban areas in Bangladesh, these include 11 city corporation, 298 pourashavas and rest are urban centres [10]. Most of these cases, people have very limited access to the proper waste management/disposal services that ultimately leads to increase the problems of waste mismanagement effectively. In addition, total rate of waste collection in major cities of Bangladesh like Dhaka is only 37%. The majorities of wastes are not collected properly and are unauthorized disposed of, which has the risks of creating serious hazard to the environmental, as well as human health [11].

2.2 Adverse Effect of Improper Management of Waste

One of the most detrimental effects of improper management of waste particularly MSW is that the irruption of diseases such as epidemic of malaria, respiratory diseases, and other water-borne illnesses due to ground water contamination. There are also bio-medical wastes which create grave danger. Approximately 20% of the biomedical wastes are highly contagious and hazardous virtually, because these are commonly disposed of into the drains and sewage system [12]. This poor sanitation has some serious concerns for the health of the citizens and is directly responsible for most of the child mortality. Besides, MSW clogs up the drainage system resulting flooding in the streets. Moreover, among the negative effects mosquitoes and bad odour are resulted. In many countries including Bangladesh, landfills cause emission of methane which is an agent for climate change. The sanitary landfill at Matuail near Jatrabari, Dhaka releases the methane which is almost equivalent to those released from 190,000 cars [12].

3 WASTE TO ENERGY TECHNOLOGIES

To attain the sustainable solid waste management, few options are considered round the world, like thermal treatment, biological treatment, landfilling with energy recovery, and recycling. Among them, thermal treatment, biological treatment and landfilling with energy recovery are supported the theme of energy recovery option of MSW management hierarchy [13]. The following sections describe the popular WTE technologies for MSW management.

3.1 Incineration

Incineration is one of the most effective WTE technologies employed for conversion of industrial, household and agriculture wastes into energy. Wastes are directly burned at high temperatures (800°C) in incineration process. Heat from combustion may be used as energy source of steam generation as well as electricity [13]. To mitigate the scarcity of power supply for the city demands and to reduce spaces for new landfills, incineration process can play significant role to produce renewable energy from discarded MSW [14]. Figure 1 shows a classic incineration WTE technology [15]. First, waste is directly burned in the combustion chamber at an adequate temperature (900-950°C) using flue gas and pre-heated air. After the waste incineration process, superheated steam is produced and then it is used within a cogeneration system to produce energy and heat. The electric energy is produced by a turbine connected to a generator and the heat by a district heating system.

3.2 Bio-methanation

In Bio-methanation or Anaerobic Digestion (AD) procedure, organic components of the solid wastes are segregated and put into a closed container where the wastes are decomposed naturally in the presence of methanogen bacteria and eventually generate biogas (methane rich). The biogas produced by bio-methanation may be used to generate power or electricity [14]. In bio refineries, solid wastes are converted into liquid and gaseous biofuels. These biofuels may be used to generate power in thermal plants, heat in various regional heating systems [15]. Figure 2 shows a facility of combined heat and power bio-refinery to treat MSW [15]. In this facilities, organic fraction can be converted into biogas while inorganic fraction can be converted into solid recovered fuel (SRF) to produce syngas. An integrated gasification system with a fuels synthesis facility can convert syngas to bio-diesel, bio-jet fuel, bio-methanol or bio-ethanol [15].

3.3 Pyrolysis

In the pyrolysis process, organic matters of waste are decomposed by high temperature to become a gas comprising of molecules jointly stated as synthesis gas or syngas. The syngas produced is further combusted in several combustion engine generator sets or turbines that generate electricity. Syngas may also be used as source of energy or by product for household use likewise as industrial use [13]. Figure 3 shows a typical pyrolysis process of biomass waste to produce energy [15].

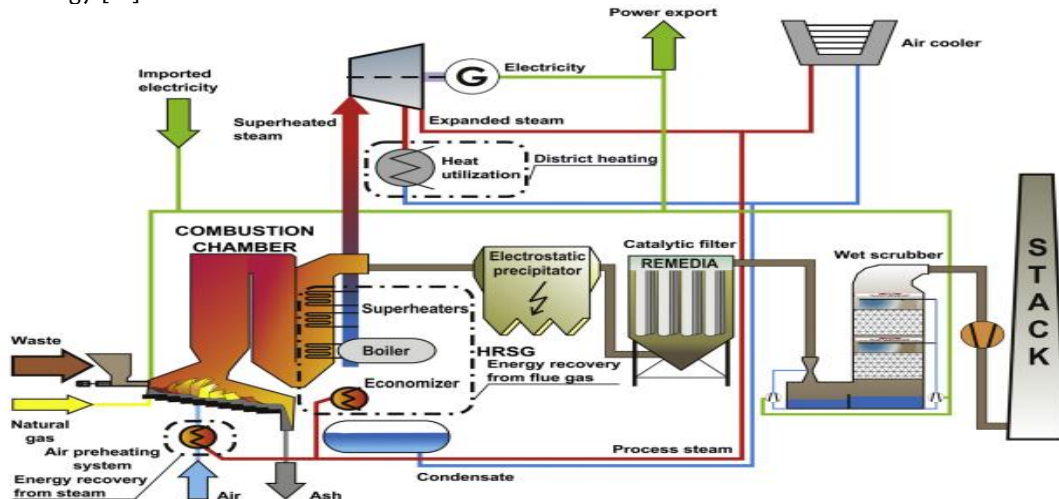


Figure 1: Incineration plant to produce electricity and heat from MSW [15].

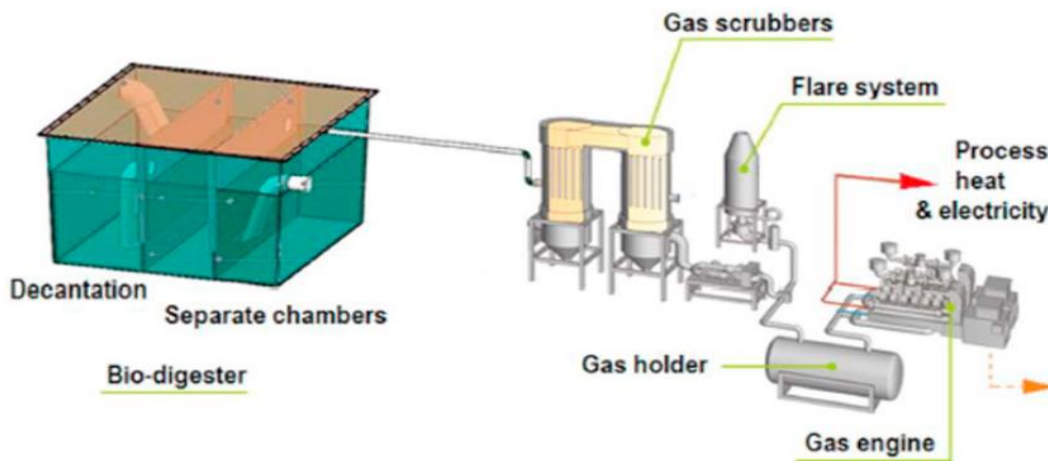


Figure 2: Combined heat and power bio-refinery to treat MSW [15].

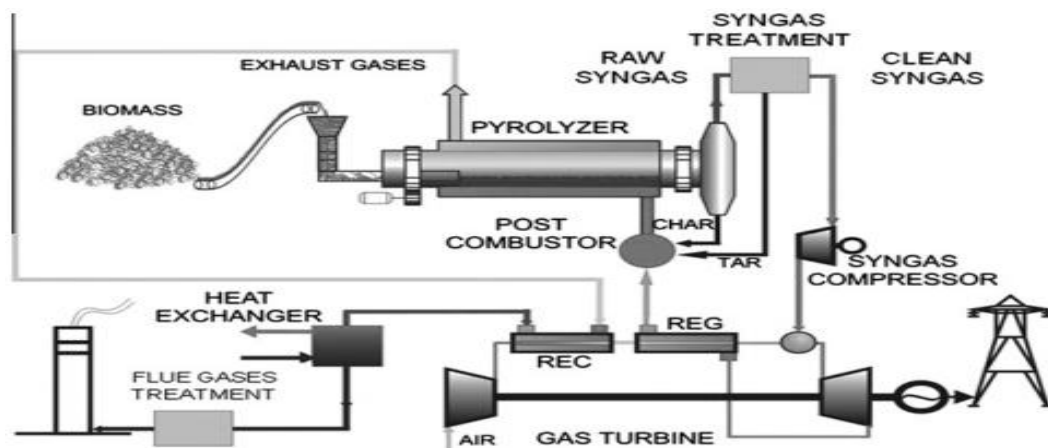


Figure 3: Representation of a pyrolysis process [15].

3.4 Landfill Gas (LFG) Collection

Landfill gas collection processes are of two types: active and passive process [16]. LFG is a natural by-product of the decomposition of organic matters of solid wastes in landfills. Landfill gas recovery process can generate 20% to 30% methane. By adopting active gas collection process, significant amount of electrical energy can be generated from solid waste which could meet the electricity scarcity of the country [16]. Figure 4 shows a typical flow diagram of electricity generation from landfill biogas [15].

3.5 Plasma Arc

Plasma arc process is considered to be one of the updated technologies for disposing of solid wastes, particularly hazardous wastes and radioactive wastes [15]. In the process, wastes collected from various municipalities are processed through the employment of high-energy plasma torches. Hence, many successful experiments have been carried out involving the gasification of MSW, fossil fuels, auto shredder residue, industrial wastes in a plasma reactor to produce primarily carbon monoxide and hydrogen. In addition, the inorganic components of the feed are converted to molten and organic wastes which are utilized for the production of power through the combustion/turbine combined cycle at much higher efficiencies [17]. Figure 5 shows an artistic drawing of the plasma waste processing plant [17].

4 WASTE MANAGEMENT AND WASTE TO ENERGY STATUS

Emphasis on waste management and subsequently WTE technologies have been developing over the years worldwide. As a highly populous developing country, the implementation of WTE technologies in Bangladesh will not only help managing the wastes generated but also be able to generate electricity. Present waste management systems and WTE status of Bangladesh particularly of its major cities such as Dhaka, Chattogram, Rajshahi, Jessore, Rangpur, Gazipur, Barisal, Mymensingh and Sylhet are discussed in the subsequent paragraphs.

4.1 Dhaka City

Islam [18] investigated six different scenarios consisting of incineration process and LFG recovery system in Dhaka city shown in Table 1. Energy potential of various WTE strategies is assessed using standard energy conversion model and subsequent GHGs emission models. The study tries to seek out the absolute best scenario considering highest economic, energy potential, net GHGs emission and proposes mixed MSW incineration process that would be an effective WTE strategy for generation of electricity in Dhaka city. According to the Table 1, it is seen that Dhaka city generates wastes approximately 3,550 tons per day and the majority of the generated waste is organic which is 68.30% while other wastes belong to combined as 31.7%.

4.2 Chattogram City

Islam et al. [19] investigated the various WTE processes in Chattogram city with a view to identify the most suitable process for the city. This study emphasizes on solid waste management of Chattogram city and its best application by considering energy production, cost aspect and impact on the environment. According to their research, the daily requirement of electricity is approximately 1000 MW but the power grid can provide electricity up to 700-750 MW which causes an energy deficit of approximately 250 MW. Table 2 shows the composition of the generated wastes in Chattogram city. The city generates wastes approximately 1550 tons per day. The traditional waste management method known as landfilling causes a negative cost impact up to 76140 USD/day which is also responsible for generating 1000 ton CO₂/day. To overcome this situation, the study suggests that incineration waste management method would be most suitable for the city [19].

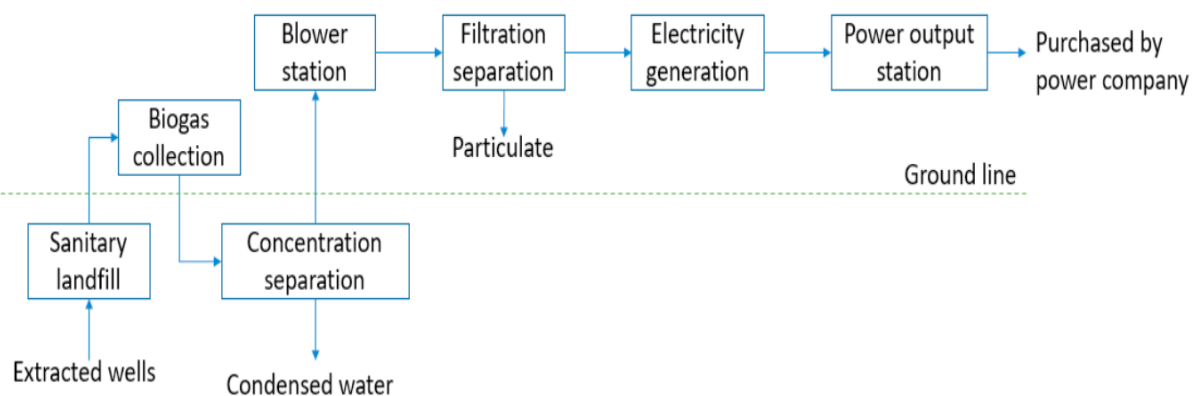


Figure 4: Flow diagram of electricity generation from landfill biogas [15].

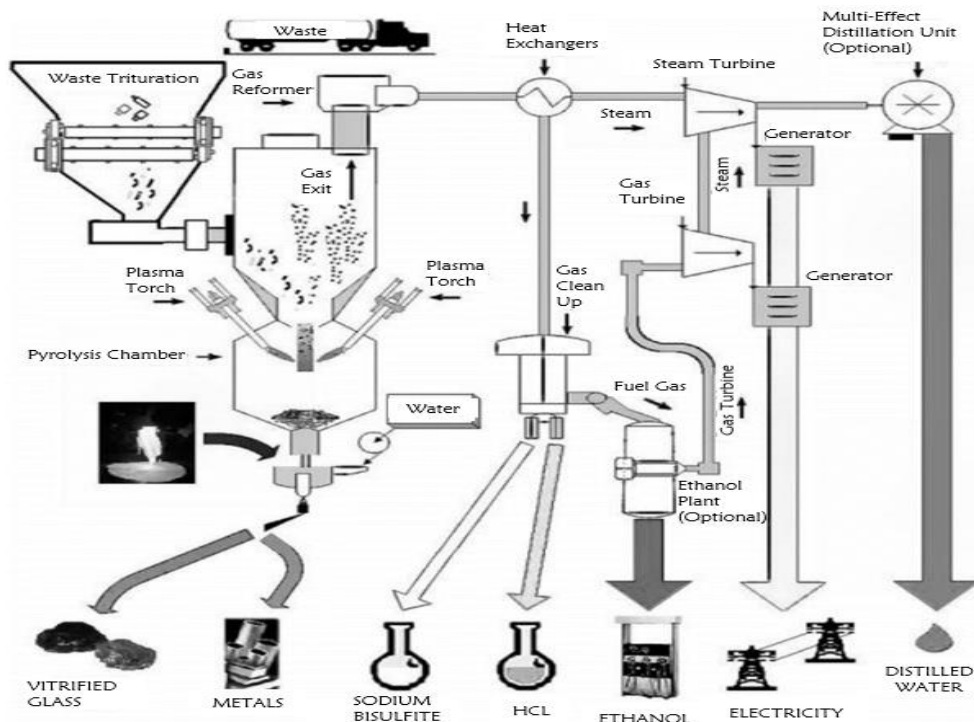


Figure 5: Plasma waste processing plant [17].

Table 1: Waste generation in Dhaka city [18]

Waste Type	Amount (tons/day)	Amount (%)
Organic	2,424.65	68.30
Plastic	152.65	4.30
Paper	379.85	10.70
Wood	78.10	2.20
Glass	24.85	0.70
Metals	71.00	2.00
Rubber	49.70	1.40
Other	369.20	10.40
Total	3,550.00	100.00

Table 2: Waste composition of Chattogram city [19]

Waste Type	Amount (tons/day)	Amount (%)
Organic	1054.00	68.00
Plastic	62.00	4.00
Paper	170.50	11.00
Wood	31.00	2.00
Glass	15.50	1.00
Metals	31.00	2.00
Rubber	31.00	2.00
Other	155.00	10.00
Total	1550.00	100.00

The parameters considered to compare between the various WTE technologies in respect of Chattogram city are demonstrated in Table 3. It can be seen that by incineration process, generation of electricity is most suitable for Chattogram city. In the analysis, for one ton of MSW, the incineration process provides an electricity of 0.585 MWh and heat of 1.742 MWh with an emission factor of 0.28 ton of CO₂. The average plant capacity cost of incineration is 2.1074 USD for one ton of MSW which is quite lower than those of other WTE technologies [19].

Table 3: Parameters considered for various WTE technologies in Chattogram city [19]

Parameter	Method				
	Landfilling	Incineration	Gasification	Anaerobic Digestion	Pyrolysis
Case Study Information					
Waste feed (ton/day)	958	958	958	958	958
Costs					
Average plant capacity cost (USD/ton waste)	14	2.1074	2.522	6.088	8.595
Operation and maintenance cost (USD/ton waste)	10	95	115	80	115
MSW Conversion Factor					
Electricity production (MWh/ton MSW)	-	0.585	0.60	0.25	0.66
Heat production (MWh/ton MSW)	-	1.742		0.2976	
Emission Factor					
CO ₂ emission from processing (ton CO ₂ / ton MSW)	0.791	0.28	0.2	0.253	1.7

4.3 Rajshahi City

Halder et al. [20] investigated the existing WTE practice in Rajshahi city. According to their study, the people living in Rajshahi city generate wastes approximately 400 tons/day. The generated wastes are from various sources such as residential, institutional, industrial, medical, construction, agricultural and municipal. The study proposed a new waste management system for Rajshahi city which is shown in Figure 6. Furthermore, in waste generation there is a seasonal fluctuation and the average MSW generation per capita is 0.40 kg/person/day. High moisture content and low calorific value also characterizes solid waste, which helps to work out the acceptable waste management option.

Supported these characteristics, an improved waste management system for Rajshahi city has been proposed by the study. Depending on the characteristics of solid wastes generated in Rajshahi city, approximately 4,482 MW/day of electricity has been generated. Based on the present solid wastes generation in Rajshahi city, the study proposed to install a power plant of 5-10 MW to produce electricity as well as to reduce adverse effect of solid waste on environment [20]. According to Table 4, the daily generation of waste in Jessore city is 21.49 ton/day and that leads to yearly waste generation of 7,846.50 tons.

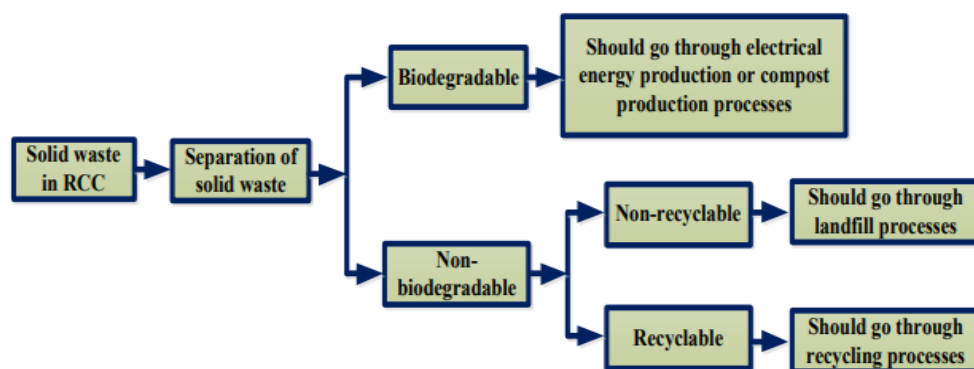


Figure 6: Proposed waste management system for Rajshahi city [20].

4.4 Jessore City

Karim et al. [21] investigated the household waste management in a particular area of Jessore city where the generated household wastes are characterized significantly in a way to store in a dumping area. According to the study, wastes are not properly managed in that particular area and people are also least concerned. During the survey, various types of household wastes were found such as biodegradable, non-biodegradable, recycling and reusable wastes [21]. Table 4 shows the generation of total waste in Jessore city.

4.5 Rangpur City

Sarkar et al. [22] investigated the waste disposal process of Rangpur city. The study intends to explain present waste management process and present state of the waste dumping points within the specific wards of Rangpur city. The prime data has been collected directly from field survey along with GPS survey to monitor and assess the dumping points of wastes. The wastes in Rangpur city are collected from four key sources: industry, residence, organization, and open street. Usually, a major portion of generated wastes are dumped on the street side which is later collected and disposed at the primary dumping points by the local cleaners. From the primary dumping points, the wastes are then collected by Rangpur city corporation (RpCC) authority and are either dumped at central dumping point or at land filling sites. According to the study, approximately 236 waste collection points are available all around the city. On an average 16.46 tons of wastes are generated per day by 15 wards of Rangpur city. Wastes generated in each wards varies with the number of waste collecting points available at the respective ward which is shown as Table 5 [22]. Based on the Table 5, for better waste management of Rangpur city, Sarkar et al. [22] suggest that Geographic Information System (GIS) may also be used as an effective tool.

4.6 Gazipur City

Shishir et al. [23] investigated about waste management of Gazipur city based on 3R (reduce, reuse and recycle) waste management policy. The goal of their research is to assess the waste generation in Gazipur city by collecting information from the household waste composition, secondary and final dumping sites in order to find out the amount of wastes that can be reduced, which will ultimately show the probable economic benefits, through the adoption of 3R policy. During the research, whole Gazipur city was divided into five zones. 10 household surveys were conducted in each zone and at the final dumping zone. According to Mohiuddin et al. [24], recyclable waste contents in Gazipur city are seen to be varied during the dry and wet seasons. The recyclable waste contents, as shown in Table 6, waste generation varies greatly by seasons which affects the waste generated per day.

Table 4: Generation of waste in Jessore city [21]

Component	Average waste (g/day)	Total household	Total waste (kg/day)	Total waste (ton/year)
Vegetable	436		18,692.21	6,822.66
Paper	8.0		358.69	130.92
Plastic	6.0		254.93	93.05
Grass & wood	21	42,793	927.22	338.44
Metal	3.5		152.45	55.64
Clothes	3.1		136.63	49.87
Glass	7.3		315.25	115.07
Others	15		659.87	240.85
Total wastes			21,497.20	7,846.50

Table 5: Ward-wise daily waste generation in Rangpur city [22]

Ward	Waste collecting points (numbers)	Waste generation approx. (tons/day)
16	12	0.87
17	07	0.80
18	11	0.98
19	30	2.0
20	22	1.5
21	21	1.3
22	19	1.24
23	16	1.12
24	22	1.50
25	15	1.00
26	14	0.98
27	15	0.99
28	12	0.82
29	08	0.50
30	12	0.86
Total:	15	236
		6.46

4.7 Mymensingh City

Rahman et al. [25] conducted investigation on Mymensingh city to identify the waste generation, waste disposal and management system in order to assess the impacts of these wastes. Through a pre-tested questionnaire from 50 industries and a recycling plant divided in categories, relevant data were collected. According to the study, total generation of waste is approximately 9.758 ton/day of which 27.42% from mustard oil industries, 34.52% from puffed rice mills, 8.89% from coconut oil mills and 13.04% from all other industries. Industries of small, medium and large category produce 1.223 ton/day, 3.115 ton/day and 5.420 ton/day, respectively. Table 7 shows the waste generation of the three categories of industries. Table 7 shows that a total of 9.8 tons of wastes are generated every day and more than 50% of these wastes are generated by large category of industry.

4.8 Barisal City

Islam et al. [26] conducted investigation in Barisal city to determine the present waste generation rate through identifying the dumping sites and evaluating the environmental effects of solid wastes. The methodologies followed for their study are field observation, collection of information and data from Barisal city corporation (BCC), photography and interviews from city dwellers. Various sources of waste generation found in Barisal city as residential (79.6%), industrial (1.2%), commercial (15.5%), open street (1.5%) and health care facilities (3.8%). Total generation of solid wastes in Barisal city is approximately 134 tons/day which are indiscriminately dumped in several 3 (three) sites [26]. Table 8 demonstrates the waste composition of Barisal city. From Table 8, it is seen that a total of 134 tons of wastes are generated every day in Barisal city and almost 65% of these wastes are of food type.

4.9 Sylhet City

Iqbal et al. [27] investigated the MSW of Sylhet city by highlighting the status of various kinds of generated wastes along with the negative impacts of poor waste management. Total waste generation per day and composition of waste in Sylhet city is shown in Table 9 and Table 10, respectively. Table 9 and Table 10 show that 67% of total 200-250 tons of waste generated each day are organic waste.

Table 6: Recyclable waste composition of Gazipur city [24]

Cycle	Average waste generation rate (kg/capita/day)	Average total waste generation (ton/day)	Average recyclable waste (%)		
			Household	Secondary dumping site	Final dumping site
Dry season	0.2774	693.5	38.16	32.066	47.46
Wet season	0.3786	946.5	41.0	27.5	37.479

Table 7: Waste generation of three categories of industries in Mymensingh city [25]

Category of industry	Total waste generated (ton/day)	Percentage (%)
Small	1.223	12.49
Medium	3.115	31.80
Large	5.420	55.34
Total	9.793	100.00

Table 8: Waste composition of Barisal city [26]

Types of waste	Amount (ton/day)	Percentage (%)
Food	87.1	65
Paper	8.16	6
Clothes	4.02	3
Polythene	10.72	8
Plastic	9.38	7
Metals	4.02	3
Wood	4.02	3
Glass	6.7	5
Total	134	100

Table 9: Waste generation per day in Sylhet city [27]

Waste types	Amount (tons/day)
Clinical Waste	5-6
Restaurant Waste	100-120
Household Waste	130-150
Total	200-250

Table 10: Waste composition of Sylhet city [27]

Waste types	%
Organic	67
Polythene	13
Metal	2
Plastic	18

5 SUMMARY

Based on the above-mentioned review, the MSW management approaches followed by the major cities of Bangladesh such as Dhaka, Chattogram, Gazipur, Rajshahi, Sylhet, Barisal, Jessore, Rangpur and Mymensingh have been reviewed according to the recent literatures. It is found that among other technologies, incineration is the most effective WTE technology for Chattogram city. Various research has also been carried out on other major cities to assess the wastes that are being generated but research on WTE for those cities yet to be carried out. Figure 7 demonstrates the total waste generation in the major cities of Bangladesh.

Figure 7 shows that maximum amount of waste is being generated in Dhaka city and Chattogram city. Dhaka generates around approximately 3,550 tons of waste per day and is followed by Chattogram is generating approximately 1550 tons of waste per day. Gazipur, Rajshahi, Sylhet, Barisal, Jessore, Rangpur and Mymensingh generate approximately 946, 400, 250, 134, 21.5, 16.5 and 9.8 tons of waste per day respectively.

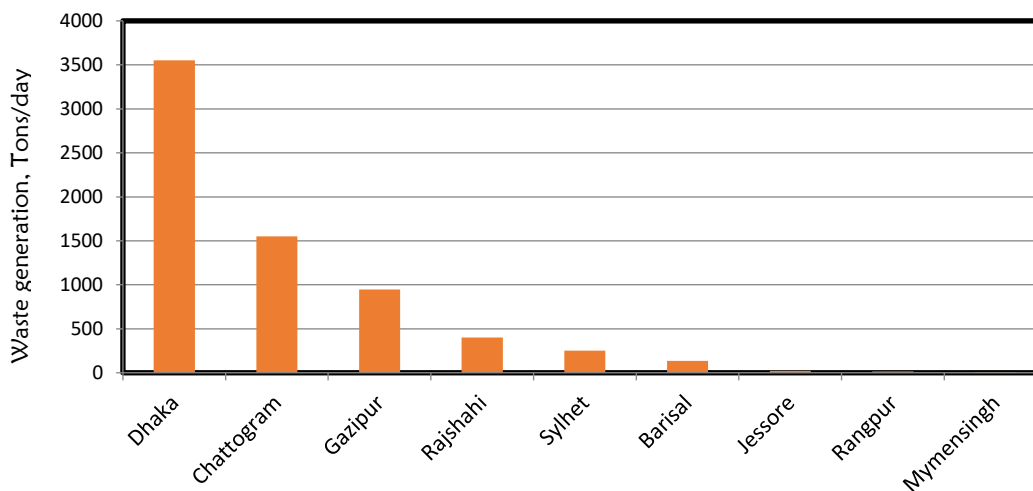


Figure7: Waste generation in major cities of Bangladesh.

6 CONCLUSIONS

The analysis of solid waste management (MSW) for the energy production by using waste to energy technologies (WTE) has been reviewed for Bangladesh perspective in this paper. It is seen that the generation of MSW and consumption of energy are increasing continuously with the rapid urbanization and population growth. However, the implementation of sustainable MSW management is turning into a great challenge around the globe in terms of environment and human health protection. WTE is a never-ending source of energy and more research in this field needs to be carried out on various areas of the country for waste management as well as energy generation. Moreover, it is seen by reviewing the relevant literature that among the WTE technologies, the incineration process can be predominantly used in the production of energy in Bangladesh. The key findings from the present analysis may be summarized as follows:

- 1) Bangladesh produces approximately 13,332 tons of waste per day. Major cities such as Dhaka, Chattogram, Gazipur, Rajshahi, Sylhet, Barisal, Jessore, Rangpur and Mymensingh generate approximately 3550, 1550, 946, 400, 250, 134, 21.5, 16.5 and 9.8 tons of waste per day respectively.
- 2) More than 26% of waste is generated in Dhaka city which is also the most populated city of Bangladesh. On the other hand, Chattogram city is seen to be followed secondly by producing almost 12% of total wastes.
- 3) The incineration process for the generation of electricity is the most effective WTE technologies for Chattogram city. For instance, for one ton of MSW, the incineration process provides an electricity of 0.585 MWh and heat of 1.742 MWh with an emission factor of 0.28 ton of CO₂. The average plant capacity cost of incineration is 2.1074 USD for one ton of MSW which is quite lower than those of other WTE technologies. Therefore, the incineration can be utilized as the most effective WTE technology for Bangladesh.

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