

ENERGY RECOVERY FROM URBAN SOLID WASTES – A CASE STUDY

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ABSTRACT

Energy recovery from Municipal Solid Wastes (MSW) generated in New Delhi is studied. The two options available viz., recovery of Biogas and energy due to the firing of MSW as fuel are reviewed. Continuous recovery of energy from the city's MSW through Biogas needs a lot of planning with respect to the design, construction, operation and maintenance of landfills. The yield of Biogas with respect to the age of landfills is often a limitation for planning purposes.

Electric power Generation (EPG) by firing MSW as fuel in the boiler-steam-turbine system is considered. The expected EPG from the city's MSW is composed using the calorific value is calculated from its composition and the one reported in literature. The results show that, the EPG is directly proportional to the calorific value of MSW fired, following an empirical relation. For encouraging results, it is suggested that, the combustible organic wastes be segregated from the MSW stream.

Keywords: Municipal Solid Waste, Energy Recovery, Calorific Value, Biogas, Boiler, Steam, Electric Power.

INTRODUCTION

In the early days, the disposal of human and other wastes did not pose any significant problems for, the population was small and the amount of land available for the accumulation of wastes was large. Now, the scenario has changed quite a lot owing to the rapid urbanization and industrialization. This has resulted in a tremendous increase in the migration of the public towards urbanized pockets. This has led to considerable changes in the socio-economic status and the subsequent infrastructural requirements for their safe, healthy and comfortable living.

In the present study, an attempt is made to explore the potential recovery of the energy available in the city's Municipal Solid Wastes (MSWs). The solid wastes can primarily be categorized based on the place of generation viz., urban, rural, and industrial solid wastes. The urban solid wastes are further classified under residential, commercial, construction activities, bio-medical treatment plant wastes based on the source of solid waste generation [Tchobanoglous et al., 1993].

The components and their percentage distribution in the solid waste stream vary in the urban and rural solid wastes [Varshney]. The term MSW considered in this study is synonymously used for urban solid wastes and corresponds to the solid waste generated from residential, commercial and construction activities. These are considered as the primary sources of the urban solid wastes. The energy recovered from them can supplement the energy available for its supply to the citizens of New Delhi. The available primary, secondary and tertiary data pertaining to the subject is utilized to accomplish the objective.

SOLID WASTE GENERATION IN NEW DELHI

New Delhi, the Union capital of our country, is currently undergoing a phenomenal population growth (an increase of ~50% from 1981 to 1991 and ~53% from 1971 to 1981). The trends are expected to continue and the city's population is projected to increase to ~128 lakhs by 2001 from the official figure of 93.70 lakhs in 1991 (i.e., 36% increase) [Doval, 1992]. The present (1998) population is estimated at 120 lakhs for calculation purposes, assuming a linear increase of population from 1991 to 2001. A total of 4000-6000 metric tonnes of solid wastes per day is being generated in the city [Ramakrishna, 1993; Basu, 1995]. The estimate is in accordance with the average per capita generation (PCG) of 0.5 Kg/day of MSW in the country [Bhojar et

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al., 1996]. Another value of the PCG of 0.33 Kg/day is also reported in literature [Bhide, 1994] for Indian conditions, in which the variation of PCG of MSW with population is not discussed in detail.

The key factor in planning the suitable waste management options is the collection efficiency of the MSW generated. The average collection efficiency in the urban centers in the country is approximated at 72% [Sinha, 1998] while for estimation purposes, 70% collection efficiency can be assumed [Bhide, 1994]. At this collection efficiency, the quantity of MSW collected in New Delhi is approximately 4200 metric tonnes per day as on 1998 @0.5 Kg/day of PCG.

CHARACTERIZATION OF MSW

Physical and chemical characteristics indicate the composition of the MSW. They are directly influenced by the local aspects such as food habits, culture, socio-economic, seasonal, and climatic conditions [Bhoyar et al., 1996]. The available MSW characteristics for New Delhi are collected from literature [Ramakrishna, 1993]. The typical distribution of the components in the MSW for low-, middle- and upper income countries (LIC, MIC, & UIC) is collected from literature [Tchobanoglous et al., 1993] and presented in Table-1. The range of physical characteristics of MSW generated from the population ranges of 0.1 to beyond 5 million, as assessed by the national Environmental Engineering Research Institute (NEERI) under Indian conditions are also collected for comparison [Bhoyar et al., 1996] and given in Table-1.

From the data, it can be seen that, the distribution of the components in MSW under typical Indian conditions and in New Delhi are more or less same except in dirt & ashes, wood, plastics and leather. The MIC data and data under Indian conditions is not matching for few components. This variation can be understandable since the figures in Table-1 represent the average values of a large amount of representative data and can deviate from the MSW composition of a specific city or country. The period and duration of data collected may also influence the variations in the composition of MSW. In fact, composition of MSW in two localities in Delhi viz., Asiad village Complex and Greater Kailash itself is reportedly differing considerably due to the socio-economic status of the residents in these areas [Basu, 1995].

Materials such as paper, plastic, leather, rubber and metals can be recovered from MSW stream indicate the extent of recycling of these constituents [Bhoyar et al., 1996]. The MSW composition for New Delhi given in Table-1 is used for subsequent calculations in this study.

ENERGY CONTENT OF MSW

The energy content of the MSW is calculated by the modified Dulong's formula [Tchobanoglous et al., 1993] given by,

$$\text{Energy content (Btu/lb)} = 145C + 610 (H_2 - \{O_2 / 8\}) + 40S + 10N \text{ ----- (1)}$$

Where C, H₂, O₂, N, and s represent the weights of carbon, hydrogen, oxygen, nitrogen and sulphur in the MSW respectively.

The exhaustive data available in the literature [Tchobanoglous et al., 1993] pertaining to the proximate and ultimate analysis of the combustible components of MSW is utilized in assessing the percentage contributions of the above elements in the MSW. The theoretical energy content or Calorific Value (CV) of the MSW is calculated as 3750 Btu/lb (8723 KJ/Kg). The CV of the MSW generated from a population of over 5 million is reported as 800 Kcal/Kg (3350 KJ/Kg) [Bhoyar et al., 1996]. The higher value of the CV (8723 KJ/Kg) may be due to the ideal conditions assumed for theoretical calculations and may not reflect the *in-situ* conditions of the MSW. It may also be due to the different compositions of the MSW taken for analyzing its properties.

ENERGY RECOVERY FROM MSW

Energy can be recovered from MSW in the following forms:

- Recovery of Biogas and utilizing its energy content
- Usage of MSW as fuel, either as-discarded basis or processed (Refuse derived fuel or RDF), for generation of steam through boilers

Recovery of Biogas

Biogas (BG) is generated due to the controlled anaerobic decomposition of organic waste or MSW. Methane or Carbon-di-oxide are the principal components of BG with methane's share is typically about 50-55% by volume [Bhide, 1994]. The typical CV of the BG is reported is 4713 Kcal/Kg (8950 KJ/Kg) [Varshney]. Sanitary landfills are used for large-scale generation of BG from MSW. The quantity

of BG generation from MSW depends upon the composition of the wastes, age of the landfills and engineered operation of landfills etc. The average BG generation rate from MSW under Indian conditions is estimated at 250 m³/tonne of MSW, which is lesser than that of 450 m³/tonne of MSW expected under USA conditions. The average yield period of BG under Indian conditions is expected to be 7-10 years [Bhide, 1994] only since, a large portion of MSW consists of rapidly decomposable food wastes having a biodegradability of 0.82 [Tchobanoglous et al., 1993]. The biodegradability is defined based on Volatile Solids (VS) content of the organic fraction of MSW. The lignin content (LC) of VS expressed as a percent of dry weight is used to estimate the biodegradable fraction. Mathematically, the biodegradability is defined by the following equation,

$$\text{Biodegradability} = 0.83 - 0.028 LC \text{ -----}(2)$$

The estimates pertaining to the amount of MSW that ultimately reaches the landfill for disposal reveal that, approximately 2/3rd of MSW that is generated reaches the landfill. The remaining 1/3rd portion accounts for the MSW – that is not collected; the fraction which is composted; recycled and burned in open pits or by other means [Bhide, 1994]. Considering these rates, the amount of MSW that is expected to reach the landfill for ultimate disposal in New Delhi is estimated around 4000 metric tonnes/day and the BG yield is expected at 10⁶ m³/day.

Pilot plant studies carried by NEERI in New Delhi indicated the presence of methane in BG @ 50-55% by volume giving a CV of 4449 Kcal/m³ (18,627 KJ/m³) of the BG generated [Bhide, 1994]. Hence the CV of the BG generated from the MSW of 4000 metric tonnes/day is expected around 1557 KJ/capita/day. The potential electricity generation from the BG is estimated by NEERI as 100 kW per acre (24.7 W per m²) for a MSW generation of 960 metric tonnes/day. However, the period for which the site would continue to yield BG is a limitation in this context. The landfill sites are usually selected in such a way that they cater to the needs over a long period of time, extending well beyond 10 years. For example, the Bhatti mines used as a landfill disposal site for the city's MSW is expected to be filled up in about 100 years at the PCG of 0.5 Kg/day of MSW [Ramakrishna, 1993]. It is reported that, about 90% of the landfills in the

country are serving merely as dumpsites rather than sanitary landfills where, provisions for extracting BG can be made [Bhide, 1994]. In this backdrop, systematic planning is required to make economical use of BG generated from the huge landfills whose life spreads well beyond 10 years.

Usage of MSW as fuel

The other option available for energy recovery is the usage of MSW as fuel. MSW can be fired in a boiler to generate steam. The steam can be converted to electric power through steam turbines. The MSW can be mass-fired (as received) or processed (RDF) before firing. However, the boiler is to be fitted with pollution control equipment to reduce the generated gaseous and particulate emissions. Typical process flowcharts are available [Tchobanoglous et al., 1993] for energy recovery by this method and the flowchart for the suggested system is given in Fig. 1.

Available [Tchobanoglous et al., 1993] data in the literature pertaining to the efficiency and loss factors for thermal processing systems is used to estimate the expected electric power generation due to the firing of MSW. The CV of city's MSW is varied viz., the calculated (8722 KJ/Kg) and that reported in literature (800 Kcal/Kg or 3350 KJ/Kg) in the estimation. The potential electric power generation from the city's MSW (1998 status) is estimated as 80.13 MW and 30.78 MW respectively for the above CVs at 70% collection efficiency of MSW.

Due to the variations in the above results for the same source, it is attempted to establish a correlation among the variables involved in the estimation. An empirical relation is generated between the expected electric power generation (P, Watts) and the CV of the fuel (Q, Joules/s). It is to be noted here that, the term 'Q' denotes the CV of the overall MSW generated i.e., per capita generation times the population. The empirical relation can be written as,

$$P/Q = 0.189 \text{ -----} (3)$$

(for the capacity of the electric generator greater than 10 MW)

In developing equation (3), the governing factors [Tchobanoglous et al., 1993] such as efficiencies of boiler and steam turbine, station service allowance and heat losses are taken into account while the power factor is assumed as 3413 Btu/KWh. The equation (3) is applied to case

studies of energy recovery from MSW given in literature [Tchobanoglous et al., 1993] and encouraging results are obtained. The equation (3) can be used as a thumb of rule in estimation of maximum theoretical electric power generation from MSW.

Observing the fact that, 'P' is proportional to 'Q', the overall CV of the MSW generated from a community but not on the PCG of MSW or the population of the community, the following aspects are arrived:

- The CV of the MSW can be increased if the organic wastes such as paper/cardboard, wood, leather, rubber, food wastes and garden trimmings etc. are segregated and used as mass-fired fuel. The collection efficiency of these wastes from the MSW stream is usually higher and hence may yield better results. The CV of these organic wastes when segregated from the city's MSW stream is calculated (9567 KJ/Kg) and found to be 10% more than the CV of the composite MSW.
- The requirement of auxiliary fuel for combusting the MSW in the boiler will be reduced. The moisture content and volatile matter of the city's segregated organic wastes is found to be 61.3% and 29% respectively. These values of the waste stream are just sufficient enough to burn without any auxiliary fuel [Bhoyar et al., 1996].
- The electrical energy recovered from MSW can be effectively utilized in satisfying the partial requirements of pocketed zones in the city such as commercial areas, where a high collection efficiency of the combustible organic portion of MSW is expected. The amount of fuel burning and the expected electric power generation will be less in such cases. An empirical relation with the same assumptions as in developing equation (3) is generated to estimate the value of 'P'. It is given by,

$$P/Q = 0.163 \text{ -----(4)}$$
 (for the capacity of the electric generator less than 10 MW)
- High degree of collection efficiency of solid wastes is needed to effectively utilize its heat potential. This warrants for increased household or door-to-door collection.
- On-site segregation of the wastes will help recover materials such as plastics and metals. This can also minimize the intrusion of inert materials such as dirt, demolition

wastes, and stones etc., into MSW and increase the effectiveness of energy recovery.

- Despite their high CV (14,000 Btu/lb or 32,564 KJ/Kg), the plastic wastes are intentionally kept out of the suggested segregated stream of combustible organic portion of MSW due to their potential high pollution problems. They need to be combusted at high temperatures (2000 °F or 1093 °C) [Tchobanoglous et al., 1993] to avoid air pollution problems.

EFFORTS BY THE LOCAL AUTHORITIES

Solid waste management is a part of the "Public health and sanitation" and falls within the purview of the powers of the State. The local Governments are therefore entrusted with the task of solid waste service delivery with their own staff, equipment and funds. In some towns and cities, it is supplemented by private agencies [Bhide, 1994].

New Delhi has been divided into three zones for the simplistic purpose of sanitation management, each under an agency [Bharati, 1995]. They are, Municipal Corporation of Delhi (MCD), New Delhi Municipal Corporation (NDMC), and Delhi cantonment Board (DCB). The VIP zone of Chanakyapuri, India Gate and the locations of Union Government offices in its vicinity, commercial area such as Connaught Place comes under [City Map, 1993] NDMC. The Delhi Airport, Palam, and Cantonment area comes under DCB while rest of the city comes under MCD. The MCD has been sub-divided into eleven zones [Bharati, 1995] for operational purposes. Available data indicates that, MCD has built 1624 open dustbins (0.5 m³ volume) and 333 covered dustbins (12.5 – 50.0 m³ volume) to cater the needs [Ramakrishna, 1993]. But they are falling short of the demand. Since the majority of the city's MSW is putrescible, it should be removed before it starts decomposing in the storage bin itself. The available 200 trucks employed by the MCD to transport approximately 20,000 metric tonnes of MSW every week are reportedly not adequate [Basu, 1995]. Non-Governmental and private agencies have stepped in to solve the problem of MSW collection [Ramakrishna, 1993]. They collect garbage from houses at nominal rates based on the storey they are located. However, the municipal staff will collect the solid wastes from the municipal bins. The biodegradable and non-biodegradable portion of the household waste is

dumped in the municipal bins by the garbage collectors after recovering the recyclable portion of the wastes from it.

It is to be remembered that, the incineration plant set up at Timarpur for the city's solid waste has failed due to the unsuitability of the solid wastes [Ramakrishna, 1993; Basu, 1995]. The Government of Delhi has reportedly assured the increased efforts for household collection of solid wastes [Basu, 1995]. This strengthens the suggestions of this study that combustible organics be segregated for effective capture of electric power from MSW.

SUMMARY AND CONCLUSIONS

Energy recovery from MSW generated in New Delhi is studied. The two options available viz., recovery of BG and energy due to firing of MSW as fuel are reviewed. It is reported that, about 90% of the landfills in the country are serving merely as dumpsites rather than sanitary landfills where, provisions for extracting BG can be made. Hence, continuous recovery of energy from the city's MSW through BG needs a lot of planning with respect to the design, construction, operation and maintenance of landfills. The yield of BG with respect to the age of landfills is often a limitation for planning purposes. In Indian conditions, this is estimated as 7-10 years. The Pilot plant studies conducted in New Delhi in 1984 have also confirmed this aspect.

Electric Power Generation (EPG) by firing MSW as fuel in the boiler-steam-turbine system is considered. The expected EPG from the city's MSW is computed using the Calorific Value (CV) calculated from its composition and the one reported in literature. The results show that, the EPG is directly proportional to the CV of the

MSW fired, following an empirical relation. Two empirical relations are generated based on the capacity of the electric generator. They can be utilized for estimation of EPG from MSW. For encouraging results, it is recommended that, the combustible organic wastes be segregated from the MSW stream. It is also suggested that, the electrical energy available from MSW be utilized in pocketed areas in the city such as commercial areas where a high amount of combustible organic wastes will be generated and their collection efficiency is also expected to be higher.

REFERENCES

- Basu Soma (1995). "Burning at the seams", The Hindu Survey of the Environment '95, Kasturi & Sons Ltd., Chennai, pp. 131-134.
- Bharati Chaturvedi (1995). "Learning to help themselves", The Hindu Survey of the Environment '95, Kasturi & Sons Ltd., Chennai, pp. 133.
- Bhide A.D. (1994). "Methane emissions from landfills", Journal IAEM, Vol. 21, pp. 1-7.
- Bhoyar R.V., S.K. Titus, A.D Bhide, and P. Khanna (1996). "Municipal and industrial solid waste management", Journal IAEM, Vol. 23, pp. 53-64.
- City map (1983). *City map of New Delhi, Anonymous Publication.*
- Doval N.K. (1992). "On the brink", The Hindu Survey of the Environment '92, Kasturi & Sons Ltd., Chennai, pp. 81-83.
- Ramakrishna V. (1993). "Urban Solid Waste Management – A special reference to Delhi", Project Report submitted to Birla Institute of Technology & Science, Pilani.
- Sinha Chhabi (1998). "Open burning of municipal solid waste: State level analysis", TERI Information Monitor on Environmental Science, TERI, New Delhi, Vol. 2, No. 2, pp. 71-77.
- Tchobanoglous G., H. Theisen and S.A. Vigil (1993). "Integrated solid waste management: Engineering principles and management issues", McGraw Hill International editions, Civil Engineering series, McGraw Hill Inc., Singapore.
- Varshney A.C. "Rural waste management", Associated Publishing Company, New Delhi, pp. 99.

Table-1 Comparative characteristics of MSW in percentage contributions

Component	LIC	MIC	HIC	Indian conditions	New Delhi
Food wastes	40-85	20-65	6-30	31-57	57.71
Paper	1-10	8-30	25-60	2.91-6.4	5.88
Plastics	1-5	2-6	2-8	---	1.46
Textiles	1-5	2-10	2-6	---	3.56
Leather	1-5 ²	1-4 ²	0-4 ²	0.28-0.78 ¹	---
Yard and wood wastes	1-5	1-10	11-24	---	0.42 ³
Glass	1-10	1-10	4-12	0.35-0.94	0.31
Metals	1-5	1-5	3-13	0.32-0.80	0.59
Dirt, ashes etc.	1-40	1-30	0-10	44-54	28.80

1. Rubber, leather and synthetics
2. Rubber and leather
3. Wood wastes only

LIC: Low Income Countries, where per capita income is less than US \$ 750 in 1990

MIC: Medium Income Countries, where per capita income between US \$ 750 and US \$ 5000 in 1990

HIC: High Income Countries, where per capita income greater than US \$ 5000 in 1990

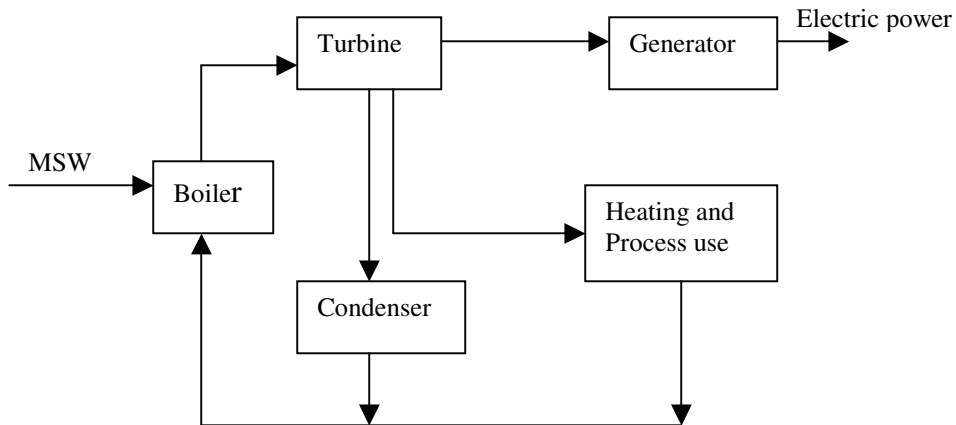


Fig. 1 Flowchart for the suggested energy recovery system from MSW