Modeling of Power Generation using Municipal Solid Waste in India

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Article Info

Article history:

Received Feb 13rd, 2012
Revised Mar 18th, 2012
Accepted Mar 25th, 2012

Keyword:

Municipal Solid Waste (MSW)
Community Dustbin (CDB)
Incineration
Cost Function
Solid Waste Management

ABSTRACT

Generation of Electrical Energy from Municipal Solid Waste (MSW) is a complex process since the waste has to undergo various unit processes before it is put in to the process of energy production. The modeling of power generation from MSW, therefore has to include all these unit processes, waste flow paths etc. The modeling must also be capable of providing information on important issues like economical, environmental among many others. With the launching of new energy policy by Govt. of India, on liberalization of energy production, Independent power producers (IPP) are exploring Municipal Solid Waste (MSW) as a main source of energy in addition to other renewable sources like fuel cells, solar, wind etc. for production of energy at affordable rates. In this paper, a mathematical model of the power generation using MSW is examined, keeping in view, the composition of waste in India. Linear equations have been developed for the various waste flow paths and the mass balance equations are then solved for the main objective function of minimum cost.

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1. INTRODUCTION

The Government of India has launched a new energy policy with which every household will have to be electrified by 2012. Considering the huge population of the country and the available conventional resources, it appears that the target seems to be unreachable. However, the Govt. has also relaxed the existing conditions for power production and is more liberalized than ever. Encouraged by this, the IPPs have been exploiting many resources to produce electricity at affordable prices. On the other hand, due to fast increasing urbanization, Solid Waste Management has become a more troublesome issue in most of the cities. Our cities are more burdened with MSW and the present practice of dumping of the waste in an open land cannot be a permanent solution. In many cities, the incineration of the MSW is being considered as one of the waste disposal methodology. IPPs and State Electricity Boards (SEB) are now considering Incineration of MSW for power generation, which gives solution for both the issues.

The power generation using MSW involves the following.

- Collection of the waste at the doorstep and the streets by the collection crew.
- Transportation of the waste so separated to a community dustbin (CDB) placed in an area
- Collection of the waste from the CDB at regular intervals and transportation of the same to a Depot where the waste are separated.
- First level of separation of the waste in to

  - Wet waste including Kitchen & vegetable waste
  - Plastics + Textile + Rubber
  - Paper +Cardboard + wood
  - Soil & building waste including Glass and metals
- Second level separation of the waste in to compostible, noncompostible, recyclable, non recyclable, combustible, non combustible etc.
- Transportation of waste to final process
- Incineration of the waste resulting into steam.
- Steam turbine running a generator

For each of these activities, there are a number of alternatives. For example, there are several separation processes depending upon the type of waste that is collected. The waste collected has to pass through several processes before it is declared fit to be incinerated for power generation .e.g. after recovering the recyclable content from a waste, only the high heat content of the remaining, should be sent to incineration. Thus a number of waste flow paths can be identified and each path can be modeled by means of a mathematical equation. The modeling of MSW for various processes is thus, very complex and was presented in [1]. The concept of MSW Fuelled Power Generation (MSWFPG) for India was presented in [2]. However, the cost estimation for entire process of power generation in India has not been obtained earlier. In this paper, a mathematical model has been studied for MSWFPG in India, considering the type of waste collection process and the suitability of waste for incineration taking the heat value of MSW into account. The cost of generation of power generation is also estimated using the prevailing processing charges and the labour charges.

2. MODEL FORMATION

Figure 1 gives the details of various processes that a waste undergoes from collection at doorstep till final disposal. From Fig 1, four major waste flow alternatives are defined, depending on the final process. They are waste to Incineration A_1- (C_0-P_1), waste to Recycle Plant A_2- (C_0-P_2), waste to Compost Yard A_3- (C_0-P_3), and waste to DumpYard A_4-(C_0-P_4).

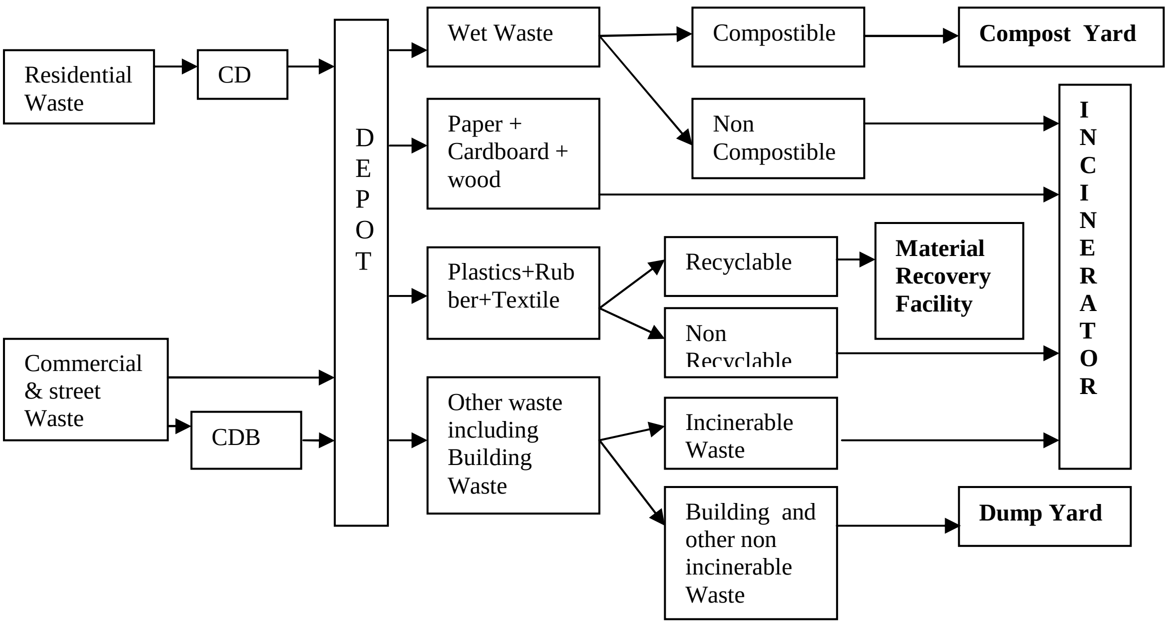

Fig. 1. Figure showing the various waste flow paths

These major waste flow alternatives can be further subdivided into number of alternatives e.g the waste that is incinerated can be from (i) the noncompostible kitchen waste after drying, (ii) the other dry Waste which is nonrecyclable and combustible and (iii) plastic which is nonrecyclable. Table 1 gives all these various flows.

2.1 Mass balance equations

A variable is defined that represents the mass of the waste that flows in a particular mass flow alternative $x(A_1)$, $x(A_2)$, $x(A_3)$ and $x(A_4)$ represents the total mass of the waste in tons / year that follows paths A_1, A_2, A_3 and A_4 respectively. The mass balance equation is then written as

$$x(A_1) + x(A_2) + x(A_3) + x(A_4) = M_{waste} \quad (1)$$

where M_{waste} is the total waste collected in tons/day

Table 2 gives the details of various processes that a waste undergoes from collection after the separation at doorstep till final disposal. The mass entering a final process can be from various unit processes. e.g. the mass that is incinerated can be either from the path E_{11} , E_{12} E_{13} or E_{14}.These waste flow paths for the final processes are given in Table 1.

Table 1. Table showing the waste flow paths

Waste Flow alternative	Path Followed
E_{11}	C-S1-S11-C32-P1
E_{12}	C-S1-C4-P1
E_{13}	C-S1-S12-C52-P1
E_{14}	C-S1-S13-C61-P1
F_{11}	C-S1-S11-C31-P2
G_{11}	C-S1-S12-C51-P3
H_{11}	C-S1-S13-C62-P4

Table 2. The details of various processes; (a) Unit Processes for Waste Management Activities: Collection; (b) Unit Processes for Waste Management Activities: Separation; (c) Unit Processes for Waste Management Activities: Transportation and (d) Unit Processes for Waste Management Activities: Final treatment

Process	Code	Process	Code
(a) **Unit Process : Collection**		Collection of Building & other non incinerable Waste after separation and transportation to Dump Yard	C62
Collection of Residential waste at doorstep and transportation to CDB	C0		
Collection of street + Building waste and Transportation to Depot	C1	**(b) Unit Process : Separation**	
Collection of Commercial waste at doorstep and transportation to CDB	C2	Separation of mixed waste into (i) Wet Waste, (ii) Paper+Cardboard + Wood, (iii) Plastics +Rubber+Textile and (iv) Building + other dry wastes at Depot	S1
Collection of Residential waste from CDB and Transportation to Depot	C01	Separation of wet waste into compostable and Non compostible	S12
Collection of Commercial waste from CDB and Transportation to Depot	C21	Separation of Plastics + Rubber + Textile into recyclable/Nonrecyclable	S13
Collection of Compostible Waste after separation and Transportation to Compost Yard	C31		
Collection of Non Compostible Waste after separation and Transportation to Incinerator	C32	**(d) Unit Process : Final Disposal**	
Collection of Platics+wood+cardboard after separation and transportation to Incinerator	C4	Incineration	P1
Collection of recyclable plastics+rubber+textiles after separation and transportation to Material Recovery Facility	C51	Composting	P2
Collection of non recyclable plastics+rubber+textiles after separation and transportation to Incinerator	C52	Material Recovery	P3
Collection of other incinerable dry waste after separation and transportation to Incinerator	C61	Open Dumping	P4

The mass balance equation for the mass that is incinerated alone is then written as

$$x(A_1) = x(A_1, E_{11}) + x(A_1, E_{12}) + x(A_1,E_{13}) + x(A_1, E1_4) \quad (2)$$

Similarly the mass balance equations for other processes can be written as

$$x(A_2) = x(A_2, F_{11}) \quad (3)$$

$$x(A_3) = x(A_3, G_{11}) \quad (4)$$

$x(A_4) = x(A_4, H_{11})$ (5)

These linear equations give the feasible mass flows of waste through the entire SWM system. Each equation can be taken and analyzed separately for the corresponding process

2.2 Model for MSWFPG

The objective function for MSWFPG can be either the cost function or the environmental factor. Choosing the cost function, the objective function is then to minimize cost U, where U = $C \cup S \cup P$, the set of all unit processes.

$$\text{Hence cost U} = \sum_{k \in W} \alpha_{u,k} x_{u,k} \quad (6)$$

where $\alpha_{u,k}$ = cost coefficient for processing waste item k at unit process u in Rs./ton.,
$x_{u,k}$ = mass of waste item k processed by unit process u tons/year and
W = set which includes all the items.

Considering Incineration alone, equation (6) can be rewritten as

$$Cost_u = \alpha_{11} x(A_1, E_{11}) + \alpha_{12} x(A_1, E_{12}) + \alpha_{13} x(A_1, E_{13}) + \alpha_{14} x(A_1, E_{14}) \quad (7)$$

where
α_{11} = the cost coefficient for processing the waste in the path E_{11}
α_{12} = the cost coefficient for processing the waste in the path E_{12}
α_{13}= the cost coefficient for processing the waste in the path E_{13}
α_{14}= the cost coefficient for processing the waste in the path E_{14}

Subject to the constraints

$$x(A_1, E_{11}) + x(A_1, E_{12}) + x(A_1, E_{13}) \geq B_0 \text{ ; } x(A_1, E_{11}) \geq B_1 \text{ ; } x(A_1, E_{12}) \geq B_2 \text{ ;}$$
$$x(A_1, E_{13});; x(A_1, E_{14}) \geq B_4 \quad (8)$$

The values B_0,B_1,B_2 B_3 and B_4 represents the average quantity of waste collected in the respective categories and are evaluated taking the past details of the waste collected and keeping in view, the change in the trend of the waste collected. The cost coefficients α_{11} , α_{12} , α_{13} & α_{14} are evaluated taking the cost of labour for corresponding processes only. Similarly the cost functions for the other waste flow paths are obtained. The equations so obtained are solved for the optimum performance of the plant itself. The final cost however includes the cost of land, equipments and the interest on the principal etc.

2.3 Power Generation and Heat Value of MSW

The heat value of MSW collected is arrived using the formulae based on the compositional analysis which requires the data of the composition of MSW. Typical heat values of the components taken from [3]. The moisture content of the waste should be considered to determine the percentage of weight of specific waste on dry basis. Typical moisture contents of waste are given in [3].

The heat value of the waste which is incinerated is then estimated using the equation

$$HV = \sum_{i=1}^{N} w_i h_i \quad (9)$$

w_i is the weight of waste of i^{th} component on dry basis
h_i is the heat value of i^{th} component.d
N is the number of components of MSW. The amount of power which can be generated is evaluated by considering the heat value.

The above equations are valid only for the residential, ancommercial wastes. The industrial waste and the hospital wastes have not been considered as they have to be treated differently.

3. CASE STUDY

A study on the waste management of Dharwad city, in south India, with a population of about 2.5 Lakh, was conducted. The city is divided into 22 municipal wards. Waste is collected everyday and is transported to the final destination which at present is landfilling. The data of the waste was collected for 6 months. The average percentage of the daily waste collected and composition is given in Table 3.

The sample waste collected was separated into dry and wet waste. The dry waste was then tested in the laboratory for calorific value which turned out to be 4436 cal/gram as against the standard CV for effective MSWFPG of 4500cal/gram [5]. Since the measured value of CV was very close to the standard CV, the proposed model was then applied to the SWM of the city. The cost considerations made towards various processes are shown in Table 4.

Table 3. Composition of daily waste collected.

Material	% of waste
Wet waste (Kitchen waste , Vegetable waste + Flower waste)	53.8
Plastic+Textile+Rubber	1.8
Dry waste (Paper + cardboard + wood)	7.2
Soil and building waste including glass and metals	37.2

Table 4. Cost consideration of various processes.

Process	Wage/employee/day
Door to door collection	Rs. 50
Waste collection from CDB and transportation to separation yard	Rs. 40
Separation of waste into dry,wet,plastics and glass/metals.	Rs. 150
Collection from separation and transportation to final process	Rs. 40
Incineration of waste	Rs. 250

Considering only the labour charges and the fuel charges for MSW handling and transportation , the cost coefficients for various processes are arrived at α11=Rs.380.64 per ton of waste, α12=Rs. 368.5 Per ton of waste, α_{13}=Rs. 478.5 Per ton of waste, and α_{14}=Rs. 370.8 Per ton of waste.

The equation is therefore to minimize

$$\text{Cost } U = 380.64\ x(A_1, E_{11}) + 368.5\ x(A_1, E_{12}) + 478.5\ x(A_1, E_{13}) + 370.8\ x(A_1, E_{14}) \qquad (10)$$

Subject to constraints

$$x(A_1, E_{11}) + x(A_1, E_{12}) + x(A_1,E_{13}) \geq 34.14\ ;\ x(A_1, E_{11}) \geq 2.259;\ x(A_1, E_{12}) \geq 2.52$$
$$x(A_1, E_{13}) \geq 10.08;\ x(A_1, E_{14}) \geq 5.2 \qquad (11)$$

The values of B_0, B_1, B_2 and B_3 were arrived at after collecting samples of MSW of all the wards of Dharwad city for six months and determining the calorific values of the respective wastes in the laboratory for their suitability for incineration. Solving the above equations, following results were obtained, pptimal solution- Rs. 53733 /ton. Taking the total waste collected per day in the city as 140 tons, the heat value of the fuel is obtained by considering the weight of the waste after deducting the moisture content of each component of waste [3] and is arrived at

$$HV = 0.12x1.292 + 0.1432 \times 9.044 + 0.67 \times 4.65 + 0.133 \times 0.1615 = 3632 \text{ Kwh/ton.} \qquad (12)$$

The dry component of the total waste which is incinerable is worked out to be 18.83 tons. Hence the total energy generated per day is 68390 kwh.

Since the waste that is processed for incineration i.e.34.14 tons, the total cost of the process turns out to be Rs 18,34,445/day. The cost of energy therefore works out to be Rs. 26.81/kwh. The cost will still escalate after considering the cost of land, equipments, interest paid on capital etc,. Since the SWM involves many other processes also, such costs are not accounted here.

4. CONCLUSION

This paper presents a mathematical model for the incineration of the MSW collected for the generation of power by incinerating the waste. The model is formulated as a linear prograing model that can be solved to arrive at an efficient SWM process, which is defined by a complete set of unit processes and the weight of each waste item handled within that unit process.

The cost of energy which is so arrived is extremely high compared to that of the energy generated from the other conventional energy sources. However, cost alone can not be taken as a criterion while deciding the power generation using MSW. The regular definition of cost efficiency cannot be used in this application since in this case; people pay the Municipal Corporation to take away their waste. Hence the revenue collected should be deducted from the overall cost before arriving at the final figure. The cost can be further reduced by educating the people to separate the waste into the above classes so that the cost of separation can be avoided.

The implementation of the project itself is a very critical step in the entire process. Because, taking a decision affecting the environment needs careful attention. The effect of today's decisions especially in the case of solid waste management will be felt during the years to come. Some decisions may have no effects for many decades. For example, it may take generations for waste containers to corrode, for their contents to leach, for leachate to migrate and pollute ground water. A decision to construct an incineration plant, similarly, will affect many people. These people should be consulted, educated before implementing the process. Scavengers, who normally collect the recyclable for their livelihood, are the first to be affected. Others include, the personnel working in the plant, the people residing nearby the plant, the people who invest in the plant all are the stakeholders in the plant. All these people rightly have a say in the planning process and their feelings have to be respected. The final economic aspects are to be considered only when these issues are settled

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