Engendering of Electricity from Waste Material: A case study in Agartala City

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Abstract:
The management of municipal solid waste has emerged as a key issue in contemporary city planning. The amount of solid garbage generated on a daily basis is forcing policymakers to implement sustainable waste management techniques. Recycling and the secure elimination of dangerous waste materials with a reasonable calorific value are both included in waste management. Considering the aforementioned fact, an attempt is made to evaluate the potential of MSW generated in Agartala city for the generation of electricity. In this study, we have analyzed two different methods to recover energy from waste such as Thermal Power-plant and Biogas Power-plant. Agartala Municipal Corporation (AMC) collects 250 MT of waste per day from different sources. In this study it is seen that 54.5 MT (22% of total waste)of waste can be used for thermal power-plant from which 1.4 MW energy can be produced. But 78% of waste is still left which can also be utilized them in Biogas power plant to produce energy.

Keywords: Municipal Solid Waste (MSW), Thermal Power-plant, Biogas Power-plant.

1.0 Introduction:

A major problem with the waste management system is waste to energy, or WTE. Regarding energy, WTE will aid in the creation of a society with reduced carbon emissions. Any waste treatment procedure that produces energy from waste sources—such as heat, electricity, or fuels like diesel for transportation—is considered waste-to-energy (WTE) technology. These technologies are applicable to a variety of waste types, including liquid, gaseous, and semi-solid waste. For processing MSW, combustion in a combined heat and power plant is the most well-known WTE technology. By burning municipal solid trash, modern waste-to-energy facilities divert waste from landfills and produce energy. Trash to Energy is a cutting edge method of disposing of trash that is well known for lowering greenhouse gas emissions, especially methane, by stopping emissions from landfills.

2.0 Literature Survey:

Arthur et al (2010) have represented a detailed study on the energy structure with respect to the biogas technology in Ghana. The paper describes the potential advantages, prospects and challenges of the biogas technology. In this paper authors illustrated energy consumption status with an emphasis laid on the over reliance on the wood fuels as source of energy by majority of households in Ghana. Particularly, the historical background and current situations of the biogas technology and endeavor to reveal the future prospects and contraventions in the dissemination of the said technology has been well furnished in the paper.

Nezih Kamal Salihoglu (2018) studied the waste to energy alternative in Turkey for the landfill gas to energy plants. The landfill gas to power plants of urban landfill was surveilled for three years and the installed capacity and actual operating hours of the gas engines were noted based on the field data parity was derived to calculate the energy capacity for such plants for a quantum of waste.

Barragan-Escandon et al (2020) studied the potential of biogas production in the Ceibales landfill in the southern region of Ecuador. In the study the biogas production potential is evaluated through mathematical models. The study considered the feeding of the produced biogas into power plant for energy generation. The mathematical model is developed and analysed by characterizing and accounting for the landfill data. The best technology for producing electricity is determined after determining each source's generating capacity.

3.0 Sources of wastes:

Waste sources can be broadly categorized into four categories:

- Industrial Waste: Waste generated in factories and other industries is referred to as industrial waste. The majority of industries pollute rivers and seas by disposing of their trash there.
- Commercial Waste: Offices, stores, colleges, and schools all produce commercial garbage.
- Domestic Waste: Domestic waste refers to the various types of waste that are gathered from household chores like cleaning and cooking.
- Agriculture Waste: Agriculture wastes are any number of wastes generated in the agricultural sector.

3.1 Biodegradable waste:

These wastes, consisting of leftover food and garden waste, originate from our kitchen. Humid waste is another name for biodegradable trash. Composting this will yield manure. Depending on the material, biodegradable wastes take a while to break down.

Figure: - 1 Biodegradable waste.

3.2 Non-biodegradable waste:

These wastes originate from the kitchen and include plastics, broken glass, and other materials. Dry waste is garbage that is not biodegradable. Dry trash has two recycling and reuse options. Non-biodegradable wastes are significant pollutants since they cannot break down on their own.

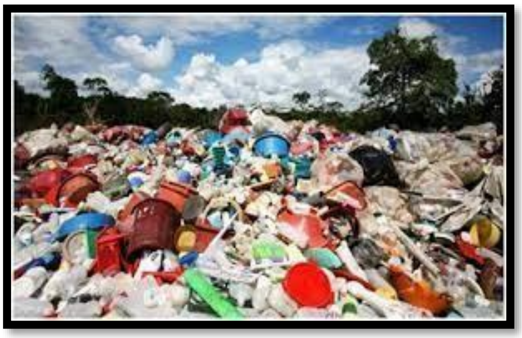

Figure: - 2 Non-biodegradable waste.

4.0 Methodology:

4.1 Study area:

Agartala, the Capital City of the state of Tripura is located at the extreme western portion of West Tripura District touching international border with Bangladesh. The city extends between 23°452 N to 23°552 N latitude and 91°152 E to 91°202 E longitudes covering an area of 62 Sq. Km. The city lieson the right bank of the river Howrah. Administratively, Agartala Municipal Corporation (AMC) comprises 35 wards. The AMC is broadly divided into four planning zones like- North, East, South and Central zones.

4.2 Primary Collection of Municipal Solid Waste under AMC

Primary collection is the practice of waste collection from its very source of generation. Primary collection includes 'house to house' for 'door to door' collection, collection of waste from commercial units like shops, hotels and restaurants. House to house garbage collection under some wards of AMC is being done by NGOs using tri-cycles and auto rickshaw. Rs. 30/house per month is beingcharged by the NGO as user fee. Efforts are going on to give the service six days in a week and to further improve the system by procuring new small autotrucks. Present Coverage: 30 to 40 %

4.3 Secondary collection of Municipal Solid Waste under AMC

Agartala Municipal Council has placed more than 500 number of medium (1.1cu meter) and large size (4.5 cu. Meter) Bins/containers by the side of major roads and in market and commercial areas. Daily more than 400 sweeping staff sweeps the roads and market areas and garbage is collected in above saidbins. Also one sweeping machine is also engaged for sweeping roads where there is footpath by the side of road.

4.4 Transportation:

Solid Waste thus generated is transported to the dump yard of Agartala Municipal Council which is about 15 km away from the main city of Agartala.On an average 25 vehicles of Agartala Municipal Council move daily twice orthrice for this purpose. As per the standard calculation about 40 vehicles makethree trips for the Dump-yard. For this 280-300 no of labours from Mechanicalsection of Agartala Municipal Council are engaged, majority in morning and some in after noon shift for lifting the garbage from the roadside and from thedrains and also from various dustbins/containers. All the vehicles of Mechanical wing are installed with GPS enabled vehicle tracking system.

4.5 Disposal of SWM at present:

At present all the garbage thus collected from the city is disposed in open in two Dump yards by way of landfill without proper processing. There is somefacility for processing of garbage at Debendra Chandra Nagar Dump yard butit is not so scientific and sufficient. Hence most of the garbage is dumped without processing. Work for Rs. 16.50 Crore, 250 Tons per day solid waste processing plant has already started at Debendra Chandra Nagar Dump yard.

4.6 Municipal Solid Waste:

As per the MSW Rules-2000, Municipal Solid Waste is a trash/garbage that isdiscarded on day-to-day basis in a human settlement and includes commercialand residential waste generated in a Municipal or notified areas in either solid or semisolid form excluding industrial hazardous wastes but including treated biomedical waste. According to Agartala Municipal Corporation approximatedaily total daily solid waste generation is 250 MT/Day.

5.0 Result and Discussion:

5.1 Calculation of WTE plant-

These solid wastes, which have around 54.5 MT of open space in the WTE plant, have the potential to produce 1.4 MW of power daily. If they are burned in this way, they could help with the nation's efforts to create aesthetically pleasing environments. The electricity produced would significantly increase Agartala's economic activity, lessen the amount of time that electricity is unavailable, and supplement the current grid electricity.

This amount of electricity would go a long way towards meeting the city of Agartala's electricity needs. The use of solid waste in this way would improve the cleanliness of city roads. The thermal evaluation of a steam boiler using solid waste as fuel is shown in this computation.

We know that,

A_f = Furnace area towards cross- section (m^2)

Cp_{fg} = Specific heat capacity (flue gas) (kJ/kgK)

CV_{sw} = Waste calorific value (kJ/kg)

$\dot{m}_{sw}$ = Mass flow waste (kg/s)

$\dot{m}_{air}$ = Flow of air mass (kg/s)

$\dot{m}_s$ = Mass flow rate of steam (kg/s)

P_e = Power (kW)

P = Pressure of condenser (bar)

Q_f = Heat solid waste (released) (kW)

Q_s = Heat of (absorbed) steam (kW)

T = Temperature (K)

W_t = Work of turbine (kJ/kg)

W_p = Work of pump (kJ/kg)

α_s = Steam enthalpy (kJ/kgK)

α_w = Water enthalpy kJ/kgK)

n_{ti} = Isentropic efficiency of turbine (%kg)

n_p = Isentropic efficiency of pump(%)

n_{gen} = Efficiency of generator (%)

n_{tm} = Mechanical efficiency of turbine shaft (%)

n_b = Thermal efficiency of boiler (%)

5.2 Combustion analysis of municipal solid waste [MSW]:

Municipal Solid Waste Contains the important elements C kg of carbon[C], H kgof Hydrogen [H_2], O kg of oxygen[O_2], N kg of Nitrogen [N_2], S kg of sulphur [S], M kg of moisture, a kg of ash.

$C+H_2+O_2+N_2+S+m+a$ = 1kg of fuel (MSW).

Following burning, water and nitrogen will be in a gaseous form. The amount of oxygen in the fuel contributes negatively to the amount of oxygen needed for combustion. The ash is not a part of the burning process. After burning, nitrogen and water are discovered in gaseous form. The process of combustion is not aided by the ash. The oxygen required for burning is negatively impacted by the oxygen present in the fuel. The following equations provide the theoretical reaction of combustion formulas of the combustible components of municipal solid waste.

$$C+ [O_2+ (79/21)\ N_2] >> CO_2+(79/21)\ N_2$$

The air in atmosphere is made up of approximately 79% N_2 and 21% of O_2.

$$H_2+0.5[O_2 + (79/21)\ N_2] >> H_2O+0.5(79/21)\ N_2 S+ [O_2+ (79/21)\ N_2] >> SO_2+(79/21)\ N_2$$

The Mass balance in the combustion chamber can be expressed as

Now, $m_{sw}+ m_{air}= m_{fg}+ m_{ash}+ m_{uf}$

$$m_{fg} = (m_{sw}+ m_{air}) - (m_{ash} + m_{uf})$$

M_{air}^{th} = O_2 required per kilogram of solid waste23.3% of O_2 in air

Where air is assumed to contain 23.3% of O_2 by mass.

= (C/12.01 +0.5h/2.016+5/32.06 -O/32)0.233.

= 0.357c + 1.064h+ 0.134S - 0.134O

Where, 12.01 u is atomic mass of carbon

32.06 u is atomic mass of sulphur

Substituting upper equations, the mass of the gas per Kg of MSW can be obtainedas -

$$m_{fg}/ m_{sw} = \{(m_{sw}/ m_{sw})+ (m_{air}/ m_{sw})\} - \{(m_{ash}/ m_{sw}) +(m_{uf}/ m_{sw})\}$$

$$= \{1- (m_{ash}/ m_{sw})- (m_{uf}/ m_{sw}) + m^{th}\}$$

$$= (0.357c + 1.064h + 0.134s - 0.134\ O) +^{ai}\{1- (m_{ash}/ m_{sw})- (m_{uf}/ m_{sw})\}$$ With

excess air of $(1+\alpha)$ ratio-Mair/ msw $=(1+\alpha)$ (0.357c+1.064h+0.1345-0.1346)

$$M_{fg}/ m_{sw} = (1+\alpha)(0.357c +1.064h +0.134s -0.1340) + (1 - m_{ash}/ m_{sw} - m_{uf}/ m_{sw})$$

5.3 Calculation of combustion air amount:

NO_2 reacts with O_2 at about 1200c and above from NO_x. So, here the fueltemperature is assumed as 1150c. So N_2 reacts is not considered here. Taking into account the combustion reaction in theory for this MSW analysis is -

1. C/12 kg + O_2/16×2 kg = CO_2 /12+32 kg
   = 12/12 + 32/12 kg = 44/12 kg
   = 1 kg +8/3 kg = 11/3 kg

2. $2H_2$/2×1×2 + O_2/16×2 = $2H_2O$/2 (1×2+16)
   = 4/4 kg + 32/4 kg = 36/4kg

=1 kg + 8 kg = 9kg

3. $S + O_2 = SO_2$
=32 + 16×2 = 32+16×2
=32/32 + 32/32 = 64 / 32
= 1 kg + 1kg = 2 kg

By weight- N_2 = 77% and O_2 = 23%By volume - N=79% and O= 21%

Assuming 30% excess air,M=m (1+α)
Now, M_{air} = 4.35[(8/5C+8H+S)-O_2]
= 4.35[(8/5×0.47) + (8×0.05) +0.009-0.29]
= 4.35[(1.235+0.4+0.009)-0.29]
= 4.35×1.36
= 5.916 Kg of air /Kg of MSW.

The calorific value of MSW was calculated using Dulong's formula-CV_{SW} = 337C+ 1419 (H_2- 0.125O_2) +933 +23N

Now, substitute all the assumed values in this formula we have-
CV_{SW}= [(9337×47.025) + 1419 (5.175- 0.125829.700) + (93×0.009) + (23×1.620)] =17968.64 KJ/Kg

5.4 Boiler efficiency:

The effective heat produced from the heating system and the heat input into the boiler from burning fuel are what directly determine the boiler's efficiency; this can be represented as

Boiler Efficiency,$n_b = Q_S/ Q_f$
= m_s (αs-αw)/ m_{sw}× CV_{sw} Here we assume the values of

Steam mass flow rate/Kg, m_S =3.437 Kg/S =12373.2 KG/hr Solid waste mass flow, m_{SW} =3.6 ton/hr =3600Kg/hr Enthalpy of water, (αw) =194.49 Kcal/Kg
Enthalpy of steam, (αs) =3248.7 Kj/kg
Gross calorific value, CV_{SW} =17968.64 Kj/KgBoiler efficiency n_b =m
=12373.2× (3248.7-194.49) ×100% (3600×17968.64)
=58%

5.5 Furnace heat flux-

The average heat flux, $q=Q_S/A_f = m_s (αs-αw)/A_f$ =25.187 W/m^2

5.6 Equivalent evaporation of boiler-

Equivalent evaporation is an important factor while determining the performanceof the boiler. The amount of water evaporation at 100°C and dry saturated steamat 100°C at normal pressure. The value of latent heat is taken as 2257 Kj/Kg.

The equitant evaporation of boiler, E= m_r (αs- αw)/ 2257Where, $m_r = m_s/ m_{sw}$
= 12373.2/3600
= 3.437 Kg/hr

(αs-αw) /2257 is a factor of evaporation and its value is always greater than 1.E=3.437(3248.7-

194.49)/2257
=4.65 Kg of steam/ Kg of fuel.

Here we assumed the values of
Pressure of steam at turbine inlet, P_4 =20 bar Temperature of steam turbine inlet, T_4=400°c
The pressure of steam at turbine outlet, P_5= 0.1 bar

Specific entropy and the entropy of the steam are as follows –
S_4 =7.130KJ/ Kgk
Now, $S_4 = S_{f5} + X_{5s} \times S_{fg5}$
Or, $7.130= 0.649+ X_{5s} \times 7.502$
Or, $X_{5s} = (7.130- 0.649)/ 7.502$
X_{5s} = 0.923 KJ/Kg
Where X is the dryness fraction of the steam.Similarly,
H5s =hf5+x5s×hfg5
=191.8+0.923×2392.9
=2393.26 KJ/Kg

A steam at turbine canhave efficiency as low as 50%.
Thus, we assumed the efficiency is 0.5.Now, $W_{inlet}=h_4-h_{5s}$ = (3248.7-2393.26) =855.432 KJ/Kg

$n_{ti} = h_4-h_5/h_4-h_{5s}$
$h_4- h_5$= (0.5×855.432) Kj/Kg$h_5= h_4$ – (0.5×855.432)
=3248.7-(0.5×855.432)
=2820.98 KJ/Kg

$W_{outlet} =h_4-h_5$ = (3248.7-2820.98) = 427.716 KJ/Kg
Ideal pump work is given by –
Assumed pump isentropic efficiency, n_p =0.7Wnet =WT-Wp
$W_p= V_f (P_2-P_1)/n_p$
$=0.001010\times (20-0.1)\times 10^2/0.7$
=2.871

W_{net} = (42.71- 2.871)
= 424.84 KJ/Kg
So now the electrical power obtainable from this design is bellow-Power= $m_s\times W_{net}\times n_m\times n_{gen}$
= (3.437×424.84) × $n_m\times n_{gen}$ KW
Assuming the values of motor and generator efficiency, we got the electric power =1.4 MW

6.0 Conclusion:

For the purpose of producing electricity, a small-scale steam boiler using combustible solid waste as fuel is thermally analysed. On the basis of the design parameters, energy utilization relations are produced and examined. The analysis's findings indicate that the amount of moisture in the flammable solid waste affects the solid waste's calorific value, and the quantity of solid waste burned affects how much steam is produced. However, the study conducted in this paper employed a calorific value of 17.49MJ/kg that was derived at a moisture content of 10%. This showed that burning 3.6 tons of solid trash per hour could produce roughly 3.437 kg/s of steam at 20 bar and 400°C. About 1.4MW of electrical power was calculated using the created steam, which can be used to generate electricity.

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