***Ambient Science*, 2022: Vol. 09(2); 22-25**
DOI:10.21276/ambi.2022.09.2.ta01

ambient
SCIENCE
Vol. 9(2):22-25
Year 2022

Published by: National Cave Research and Protection Organization, India

TECHNOSCIENCE ARTICLE

A Case Study for Analyzing the Power Generation from Wastes

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Keywords: Municipal Solid Waste, Agriculture waste, Sewage sludge, Biomass, Anaerobic Digestion

Abstract

An increase in the generation of different types of wastes in both urban, as well as rural areas and the mismanagement in handling and treating these wastes, are creating several issues for the environment. On the other hand, the increasing demand for electricity and the usage of fossil fuels for fulfilling this demand creates environmental issues. Both of these issues can be resolved if environmentally friendly methods are adopted for generating electricity from these wastes. This paper examines four types of waste available ie. Municipal Solid Waste, Animal waste, Agriculture waste and Sewage Sludge in district Faridabad in NCT of Delhi; different technologies available for converting these wastes into fuels, methods for generating electricity from these fuels and the amount of energy which can be generated. The residue left after this conversion can be used for other value-added applications.

Introduction:

The increase in population and the increase in the economy cause an increase in the energy demand. With an increase in population, the amount of waste generated increases. If waste is not managed efficiently, then it affects the environment adversely. The area under study is District Faridabad, which is spread over an area of 741 sq km in the NCT of Delhi. District Faridabad is having 144 villages and a population of 1809733 (GHF, 2022; www.faridabad.nic.in). As per NCR 2014, electricity demand in 2024 is expected to reach 69613 lakh units, which will increase to 90497 lakh units in 2027 and 117646 lakh units in 2030. Both the problems ie. energy requirement as well as waste management can be solved if different types of waste can be used for generating electricity. The residue left after obtaining energy is also useful for several applications thereby forming a circular economy.

As of 31 March 2022, 52.8% of the power generated in India is by using coal, 6.3% by gas and 0.1% by diesel (MOP 2022; https://powermin.gov.in). Coal reserves are at large distances from

Faridabad city increases the cost of fuel transportation. As per (MOPSW 2020; https://pib.gov.in) cost of transportation in Rupees per Tonne Km for three modes of transportation ie. highways is 2.5, railways 1.36 and waterways 1.06. If a generation is done near coal availability and transmitted to load then it increases transmission losses. In India, about 20.66 percent of power is lost during transmission and distribution (MPC 2021; https://cea.nic.in). These wastes serve as locally available fuel and give the benefits of distributed generation like reduced costs and transmission losses. Four types of wastes studied are Municipal Solid Waste (MSW), Animal waste, Agriculture waste and Sewage Sludge.

Energy from Municipal Solid Waste

As per Municipal Corporation Gurugram (ISW 2016; http://www.environmentclearance.nic.in) Faridabad generates 716 metric tones (MT) of MSW. Bandhwari landfill/ dumpsite is spread over 30.5 acres and is used by two districts ie. Faridabad and Gurugram.

The dumpsite is already filled beyond the limit and a separate dumpsite for Faridabad is to be set up in Pali, but it is facing objections from nearby residents. A 15 MW Waste to an Energy power plant is to setup at the site and will be operational by Dec 2023. The current situation indicated the need for efficient waste management. MSW consists of 40 to 45% organic matter, 20-30% inert matter and the rest is recyclable matter (NAP, 2015; https://cpcb.nic.in). Maximum utilization of MSW depends upon the efficient collection of wastes. For residential areas and housing societies door to door collection is a good option. For other unregularised residential areas, waste is thrown in open at any nearby place which needs to be collected. Segregation of waste is the next step. The recyclable items can be separated and sent for reuse. An inert matter like sand, mud and construction and demolition waste can be separated and can be processed and used. The organic matter present in MSW can be used for generating electricity.

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DOI:10.21276/ambi.2022.09.2.ta01

MSW generated per person for the duration 2022 - 2035 is 0.4 kg (NCR, 2014; https://tcpharyana.gov.in). Equation (1) gives yearly MSW generated (Singh & Leena, 2019): Yearly MSW generated (in MT) = (Population * MSW generated per person per day (in kg)* 365)/1000 (1)

For the population of Faridabad as 1809733, we get 1809733 * 0.4 * 365/1000 = 264221.018 MT or approximately 723 MT per day which is near the data available with Municipal Corporation Gurugram.

MSW collection efficiency needs to be stepped up; 90% to 100% collection efficiency will give 644 to 716 MT of MSW (considering the data from Municipal corporation Gurugram). The useful organic matter being nearly 45% of this gives 289 to 322 MT of raw fuel for obtaining energy. Two common methods for generating electricity from MSW are i) Incineration in WTE plants and ii) Anaerobic Digestion (AD) producing biogas.

i) Incineration in WTE plants: in these power plants, the MSW is preprocessed and fed to the boiler for producing steam (similar to coal-based thermal power plants). Direct combustion of MSW causes carbon emissions. This makes Carbon Capture and Utilization (CCU) mandatory. The carbon content in the exhaust gases is captured and can be utilized for various commercial applications like oil gas recovery, chemical production, mineralization, desalination and water production, etc. Energy generated from WTE plants is given by equation (2) (Singh and Leena, 2019):

Electricity Generated (in kWh) = (Useful Waste (in MT)*Gross Calorific value*1000)/ Heat rate (2)

Considering the gross calorific value of 1319 Kcal/kg and heat rate of 3500 Kcal/kWh, the available useful MSW can generate 108 to 121 MWh of electricity every day.

ii) Anaerobic Digestion of MSW: it consists of the action of microorganisms on organic matter like food waste, garden/plant wastes, animal and other similar wastes in the absence of oxygen and produces biogas. Biogas consists of methane (50-75%) having 36 MJ/m^3 calorific value and can be used as fuel (similar to natural gas)(Berktay, 2008). This biogas can be used as fuel in boilers to produce steam. Also, biogas-powered engines can be coupled with generators for electricity generation.

Table-1 gives the amount of biogas produced in normal cubic meters per MT for different types of biomass. The methane content in the biogas depends on the type of substrate used. It is approximately 62.5% when using animal waste as substrate but is lesser (approximately 52%) when using food waste. Animal waste is already digested once in the body and digesting it again in the digester gives less biogas as compared with plant wastes. Another factor is the C/N ratio which is low in animal waste. (Khanal, *et al*, 2019) For an efficient AD process, the C/N ratio should be 20:1 to 30:1. Agriculture wastes are having high carbon content whereas animal wastes are having high nitrogen content. Codigestion (combining two types of substrates for AD) increases biogas production. Two technologies for power generation using biogas as fuel are in Table-2:

Table 1. Biogas produced from different types of biomass (Source: Tamburini *et al.* 2020)

#	Type of biomass	Biogas (Nm^3/MT) Fresh matter
1	Pig waste	10.4 ± 0.4
2	Cow manure	63.3 ± 7.5
3	Poultry manure	97.8 ± 6.4
4	Poultry litter	241.6 ± 21.3
5	Tomato residue	101.8 ± 18.7
6	Potato residues	126.8 ± 3.5
7	Vegetable, fruit and legume waste	158.1 ± 18.7
8	Beet pulp	104.5 ± 13.6
9	Grapes and vinasses	150.0 ± 12.1
10	Slaughterhouse waste	102.5 ± 0.4
11	Edible oil residues	301.0 ± 9.3
12	Crop/Agriculture residue	124.4 ± 4.9

Table-2: Technologies (thermal) for generating power from biogas (Barragán-Escandón *et al.* 2020)

Technology	Flow (m^3/min)	Power Gen. (MW)	Elec. Efficiency (%)
Turbine	> 40	> 3	25-40
Micro Turbine	< 8	0.03 – 0.2	26-32

As per (Vaid & Garg, 2013) 4m^3 of biogas generates 5 kWh of electricity. Using this data gives 43 to 70 MWh of electric energy generated in a day.

Energy from animal wastes

From the data available with AHD 2019 (http://pashudhanharyana.gov.in/) in the 20th livestock census 2019, Faridabad is having livestock population as shown in Table-3.

Table 3. Livestock population in Faridabad

Livestock	Population	Livestock	Population
Cattle	42988	Buffalo	114183
Pig	1562	Sheep	3721
Goat	6790	Poultry	57800

The amount of biomass (dung) available from different animals/birds depends on the feed and age. Amount of biomass available from different livestock is shown in Table-4 (Kaur *et al.*, 2017).

Table 4: Biomass available (Kg per day) availability from livestock

Livestock	Biomass	Livestock	Biomass
Cattle & Buffalo	10-20	Pig	4
Sheep & Goat	2	Poultry	0.1

Taking average cattle and buffalo waste to be 15 kg per day gives 2357565 kg; from pigs, the biomass available is 6428 kg, from sheep and goats is 21022 kg and from poultry birds, it would be 5780 kg per day. Anaerobic digestion of animal waste gives biogas. The amount of biogas obtained depends on factors such as pH value, temperature, carbon to nitrogen (C/N) ratio, etc. Approximate biogas yield from

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animal waste is 63.8 m^3 per tonne, from poultry birds it is 97.8 m^3 per tone (as in Table 1). Collection efficiency of this livestock can be made very high. About 152717 m^3 of biogas can be generated from the waste available in one day which gives 190.9 MWh of electric energy generated in a day.

Energy from agriculture waste/residue

As per ACP 2011 (https://agricoop.nic.in/), the Gross cropped area in Faridabad is 215 hectares with rice as the major crop in Kharif season and wheat in Rabi season. Rice is cultivated in 27.4 hectares and wheat in 104.8 hectares. The wheat crop residue left can be used in animal fodder, but rice crop residue is not useful as fodder. To get rid of this residue, farmers burn it which creates environmental issues and also a loss of an energy source. The residue can be used to generate electricity either by waste to energy power plants (similar to MSW waste to energy) or they can be used for producing biogas by AD. From 27.4 hectares of area, nearly 130 metric tons of waste is available which on used as fuel in WTE power plants and can generate approximately 49 MWh of electricity. By using this agriculture waste as feedstock for AD, 16120 m^3 biogas can be produced which will give 20 MWh electricity with the digested slurry further useful as manure.

Energy from agriculture waste/residue

Wastewater needs to be treated before being discharged into water bodies, failing to do so contaminates the environment. Sewage sludge is left behind as residue after-treatment of wastewater in sewage treatment plants (STP). The composition of sewage sludge is highly variable and may depend on many various factors such as the seasons, the technology applied in STP, the specificity of the source area of the influent, etc. On an average, sewage sludge contains 50%–70% organic matter and 30%–50% mineral components (including 1%–4% inorganic carbon), 3.4%–4.0% nitrogen (N), 0.5%–2.5% phosphorus (P), and significant amounts of other nutrients, including micro-nutrients that can be recovered. So, wastewater should be considered as a source of water, then energy, organics, metals, and other resources. Due to this, it is better to consider sewage sludge as a source of renewable energy and material recovery. Wastewater contains a lesser amount of lignin and cellulose which makes its decomposition faster and so its treatment is a prime task so as to minimize the production of pollutants produced by the decomposition (Rorat *et al.*, 2019). Treated wastewater finds applications in irrigation, toilet flushing, and groundwater replenishing and can be further purified for household and industrial purposes. Faridabad is on the banks of the river Yamuna. Faridabad city is open defecation free. Wastewater is collected by the sewage system, which covers 638 km. Further, the onsite containment system is built with septic and fully lined tanks. The outlets of these tanks are connected to the sewage systems. There are 11 intermediate sewage pumping stations and 3 main pumping stations with 3 STPs in the city having an installed treatment capacity of 140 MLD and 117 MLD is reaches the inlet of STPs. About 40% of wastewater is lost in leakages from sewer lines (SFD, 2020). AD of sewage sludge produces biogas and the digested sludge can be used as manure. Total sludge production is nearly 225 Kg per 106litres, which gives total sludge generated between 26325 Kg per day. Total 1 kg of sludge produces 0.6 m^3 biogas (Malik & Bharti, 2009). On an average 15795 m^3 biogas can be produced from the sludge which gives 19.7 MWh of electricity per day.

Hydrogen production from biogas and electricity generation from hydrogen

Methane present in biogas can be used for producing hydrogen by Steam Methane Reforming (SMR) process. SMR takes place at a high temperature of 700 1100°C. The reaction between steam and methane is

$$CH_4 + H_2O \rightarrow CO + 3H_2 \ldots\ldots\ldots\ldots (1)$$

Another reaction for increasing the hydrogen production is between carbon monoxide and water taking place at a lower temperature of 360°C as x

$$CO + H_2O \rightarrow CO_2 + H_2 \ldots\ldots\ldots\ldots (2)$$

These equations indicate that high amounts of carbon dioxide and carbon monoxide are produced in the process which needs to be captured (Collodi, 2010).

Hydrogen is used as fuel in a fuel cell to produce electricity. Fuel is classified on the basis of electrolyte used (Alkaline Fuel cell, Proton Exchange Membrane Fuel Cell, Phosphoric Acid Fuel Cell, Molten Carbonate Fuel Cell and Solid Oxide Fuel Cell), but all of them operate on the same basic principle where hydrogen supplied to the anode of fuel cell combines with oxygen (available from the air) at the cathode to produce electricity with water as a by-product. Fuel cells do not emit any pollutants and so it is environmentally friendly. Fuel cells are having good efficiency (40-60%). Fuel cells find applications in different areas like electronics, housing power, power plants, electric vehicles, and even in military applications. Different types of fuel cells operate at different temperatures ranging from 65°C to 1000°C. For Alkaline Fuel Cell (AFC) and Proton Exchange Membrane Fuel Cell (PEMFC), pure hydrogen is used as a fuel. For Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC) and Solid Oxide Fuel Cell (SOFC), biogas and purified syngas can also be used as fuel. MCFC operates on temperatures ranging from 650-700°C and SOFC operates on temperatures ranging from 600-1000°C. Their high operating temperature makes them more suitable for combined heat and power plants (Fan *et al.*, 2021).

Discussion and conclusion

Different types of waste can be used as a resource for obtaining energy and this is a renewable source. The whole process of obtaining energy from waste is highly dependent

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on the efficiency of waste collection. The whole of the waste generated is not collected and a huge investment is needed to ensure maximum collection. Low-cost manpower is available which is beneficial for this and using this manpower along with necessary transportation arrangements the waste collection can be maximized. Close monitoring of the entire process of waste management and power generation is needed. Segregation of waste is needed and the technique suitable for each type of waste can then be selected. Different emissions during the entire process should be within the specified norms. Approximately 2% of Faridabad's electricity requirement can be fulfilled by utilizing different types of waste. The byproducts left are also used in other applications like manure which makes the processes economically feasible thereby making a circular economy.

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