Municipal solid waste biorefinery: Case study of 100 TPD mechanical-biological treatment plant

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Abstract
A long-term feasibility analysis of a 100 ton per day MBT plant for MSW valorization and material and energy recovery was carried out. It involves the material recovery and segregation stage (MRSS), organic extraction (pulping), thermophilic anaerobic digestion (AD), composting, effluent treatment plant (ETP), and biogas genset stages producing: 11.90% recyclables, 33% refused derived fuel (RDF), 5% compost, 70 m^3/day recyclable water and 0.435 MWh/day electricity. The biogas and methane yield were 0.535 and 0.350 m^3/kg VS_{added} (avg.), respectively, with 40% VS removal (avg total solids (TS) 10%). Less than 3% (inert) of total waste received was subjected to landfill disposal. The MBT plant's revenue generation is 995 US$ per day/ 148 tons ($ 6.72/ ton) waste processed. The gross OPEX is 24 US$/ton making the net OPEX of 17 US$/ton (minus revenue), which could be considered as the excellent OPEX for MSW based MBT plants as per global benchmarks. As per LCA study, the total GHG emissions have been calculated to be -25.68 tons CO_2 eq./100 tons MSW. The negative emissions result from the export of electricity, compost, and RDF as well as recycling of paper and plastic products.

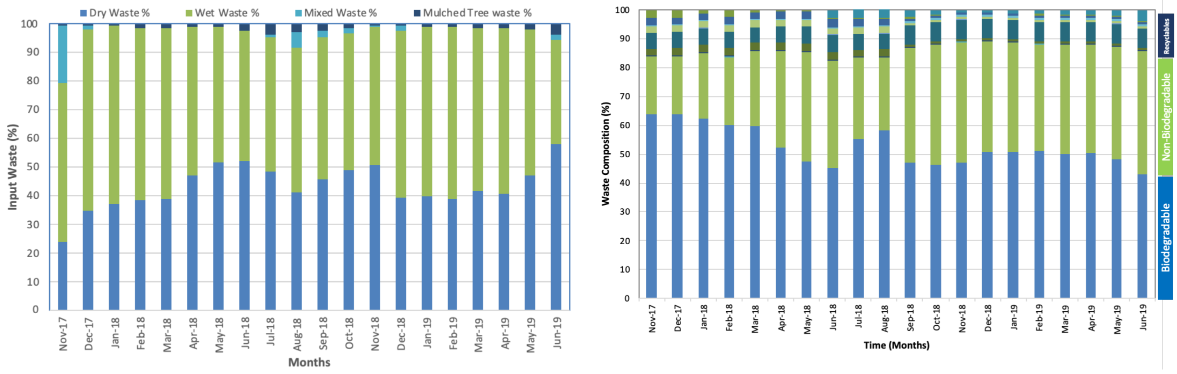
Keywords: Anaerobic digestion; Biogas; Mechanical biological treatment; Municipal solid waste

1. Introduction
Recently, India's first state of the art waste to energy plant based on mechanical biological treatment (MBT) process has been launched in Saligao, North Goa, which utilizes 100 tons of MSW per day to generate 0.8 to 1.0 megawatt hour (MWh) of energy. In developed countries, many small bio-methanation plants are working successfully on segregated wet waste (pre-dominantly of agri-waste, chicken feed, piggery waste etc.). However, in India the Goa MBT plant has the first successful bio-methanation plant to operate on municipal solid waste using effective segregation and pulping technique. The MBT facility is designed to recover recyclables from the waste, segregate the waste into dry (RDF for energy recovery) and wet fractions using organic extrusion followed by bio-methanation of the wet portion, generate electricity and compost. The techno-economic and energetic analysis of these project is necessary to realize the practicability of MBT systems in developing countries, where MSW consist of more than 60% of organic waste and the recyclables fraction as well as quality of such recyclable material is way lesser than those in developed countries. In this study, a broader assessment has been provided on the potential of MBT processing of MSW for India. This paper carried out a comprehensive evaluation (for two years) of the energy, environmental, and techno-economic feasibility of the MBT system comprising material recovery facility, bio-methanation, and effluent treatment plant, rotary and windrow type composting, and biogas to electricity generation unit.

2. Material and Methods
The MSW treatment facility of 100 tons per day (TPD) treatment capacity is based on a mechanical biological treatment (MBT) technique and located in North Goa, India. It is designed to recover recyclables from the waste, segregate the waste into dry and wet fractions using organic extrusion followed by bio-methanation of the wet fraction, generation of electricity, and compost. The facility was receiving waste from various panchayats in the range of 130 to 173 TPD based on seasonal variations and advent of tourist season. The Inlet and outlet samples were collected to evaluate the performance of anaerobic digesters (feed and digestate) and effluent treatment plant (ETP) (influent and effluent). All the experiments were carried out as per Standard Methods (APHA, 2005). The biogas volume and composition were measured by an ultrasonic flow meter (Krohne Optisonic 7300, Denmark) and a biogas analyzer (INCA 4000 T100, AMCS, UK), respectively. Lifecycle Greenhouse gas (GHG) emissions analysis has been carried using MS Excel® software, adopting a process matrix approach for inventory analysis.

3. Results and discussion
3.1. Waste composition and quantity

The MBT plant received a solid waste volume of 130-173 tons/ day (avg. 148 tons/ day) during the study period (Nov. 2017-June 2019). The input waste volume (avg.) has been characterized in four fractions: dry waste (64 tons/day), wet waste (80 tons/day), mixed waste (2.5 tons/day) and mulched tree waste (2.4 tons/day), which shared a percentage fraction of 43.07, 53.45, 1.79 and 1.68%, respectively (Figure 1a). The wet waste shared the highest fraction of total waste composition followed by dry waste, mixed waste, and mulched tree waste. The MSW included recyclables – 10 to 14% (avg. 11.90%), organics or bio-waste – 45 to 60% (avg. 52.60%), inorganics/RDF – 20 to 35% (avg. 33.30%) and, inert and mulched tree waste around 2% (Figure 1b). The organic (biodegradable) waste added the highest volume to the total waste followed by RDF, recyclables, and inert.



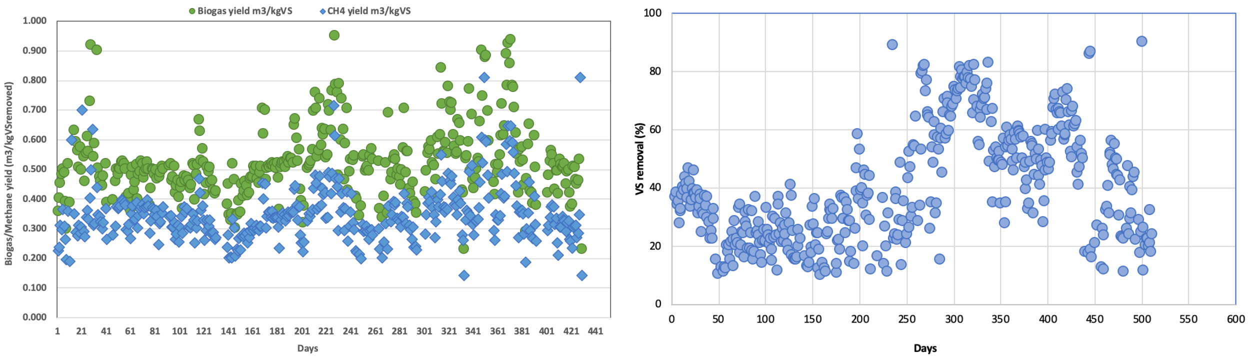
(a) **(b)**

Fig. 1. Input waste fractionization (a) and waste characterization (percentage composition) (b)

3.2. Performance of AD

3.2.1. Biogas generation

Figure 2 shows the profile of the biogas and methane generation and yield. The average biogas and methane generations were 5000 and 3250 m^3/day, ranges from 2065 (min.) to 10725 (max.) m^3/day, and 1300 (min.) to 7220 (max.) m^3/day, respectively. The biogas and methane yield (avg.) were 0.535 and 0.350 m^3/kg VS_{added}, with a yield range of 0.235 (min.)- 1.206 (max.) m^3/kgVS_{added}, and 0.140 (min.)- 0.812 (max.) m^3/day, respectively. The OLR values in our study ranges from minimum to maximum of 0.28 to 3.26 kgVS/m^3.day, with an average value of 1.82 kgVS/m^3.day. The average CH_4 and CO_2 content in biogas were 65 and 35%, with a min to peak values of 45 – 78% and 22 to 55%, respectively. The average H_2S concertation in biogas was observed to be 61 ppm with lowest to highest bandwidth of 1 to 693 ppm. On 60% times, the H_2S concertation in biogas was found less than 10 ppm. However, the H_2S concertation ranges from 10-100 ppm on 25% occasions. The anaerobic digester was operating at an average total solid (TS) % of 12-15%. The findings revealed that the AD system achieved an average VS removal of 40% during the study period.

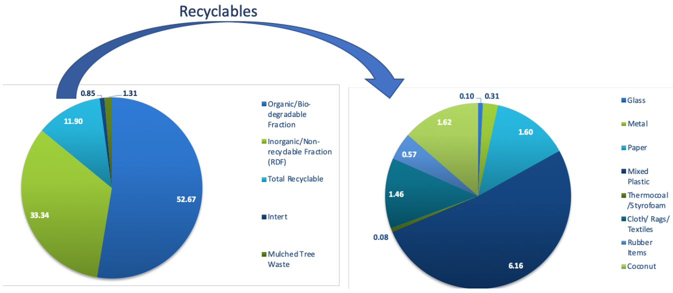


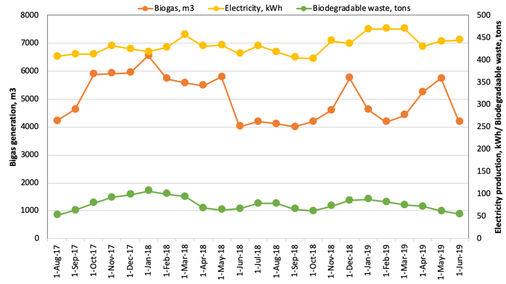
(a) (b)

Fig. 2. (a) Biogas and CH_4 yield and (b) percentage VS removal in AD

4. Material recovery, recycle and revenues

The raw waste comprised of an average 11.90% (17.60 tons) of recyclables (Figure 5a). The composition of recyclables (avg. 11.90%, 17.60 tons) has been apportioned as: glass- 0.10% (0.15 tons), metal- 0.31% (0.46 tons), paper- 1.60% (2.38 tons), plastic- 6.16% (9.11 tons), thermocol- 0.08% (0.11 tons), cloth- 1.46% (2.17 tons), rubber- 0.57% (0.84 tons), and coconut- 1.62% (2.39 tons) (Figure 5b). The plastic waste (mixed plastic, PET bottles, cups, food packets, coated plastics) added the highest fraction of recyclables.





(a) (b)

Fig. 3. (a) Average composition of MSW and recyclables (a); (b) monthly average electricity generation

The RDF, comprised of waste plastic, textiles, wood, paper, etc., is a substitute fuel generated from the combustibles in MSW. The raw waste comprised of an average 33.34% (49.10 tons) of refuse derived fuel (RDF) (Figure 3a). RDF generated from the waste has a calorific value in the range of 4500 to 5500 Kcal/kg, which is comparable to those reported by earlier studies. Figure 3b shows the monthly average of electricity production from biogas genset. The average electricity generation in the plant was 0.315 MWh from the waste treated. As only 2 ×170 kWh (340 kWh) gas engine installed at the plant site, the plant was capable to produce only upto 340 kWh of electricity. The biogas flaring system works for at least 6-7 h daily, due to which approximately 2000 m^3/ day of biogas has to be flared. Calculating 2000 m^3.day/ 24 h= 84 m^3/h ≈120 kWh of power, thus the average power potential is 315 + 120 = 435 kWh or 0.435 MWh/day from corresponding biodegradable waste treated of 77 tons (min. 55 tons, max. 106 tons) and 5000 m^3 (min. 4000 m^3, max. 6550 m^3) biogas produced.

5. Economic analysis

The recyclables are traded at 0.015 US$ per kg, making the per day revenue of US$ 264. The Government of Goa procures an average electricity generation of 0.435 MWh for $ 0.071 per unit, which added $731 in revenue generated from per day electricity feed to the power grid. Thus, the total income of US$ 995 is made per day for 148 tons MSW processed, which equals to $ 6.72 per ton of waste processed per day at MBT plant, and approximate revenue generation of 0.36 million US$ per year. The compost is mostly taken free of cost by farmers, whereas RDF has a disposal cost. The main heads in operation and maintenance expenses (OPEX) are electricity, manpower, diesel, RDF disposal, spares, chemicals, and miscellaneous, which contributed to the average OPEX of US $ 24 /ton (148 ton per day ×$24/ton = $ 3552 per day/148 ton waste treated). Calculating the total revenue generation of 0.36 million$/y ($ 6.72/ton) and total OPEX of 1.30 million$/ y (US $ 24 /ton), the net OPEX is 0.94 million$/y ($ 17/ ton). The RDF generated (apprx. 48 tons per day) at the plant has been transported to the cement factories, i.e., 200-500 km away from the MBT plant, at the cost of $ 9.3 per ton. RDF can be used locally also by industries for burning and heat generation, provided such sectors are equipped with proper incinerators (rake design, minimum temperature, etc.). Thus, the OPEX can further reduce to 0.77 million $/y (US$ 14 per ton) by removing the RDF transportation cost and used it locally. Globally, 18$/ton is considered an excellent OPEX for MBT plant, where 14$/ton OPEX of Goa MBT plant is significantly lesser than that.

5. Lifecycle Greenhouse gas (GHG) emissions

The total GHG emissions have been calculated to be -25.68 tons CO_2 eq./100 tons MSW. The negative emissions result from the export of electricity, compost, and RDF, which are expected to replace the grid electricity, fertilizers, and fuels derived majorly from fossil sources. The majority of the negative emissions are attributed to the recycling of paper and plastic products. The products recycled by the MBT plant are expected to replace the new products in the market and avert the emissions associated with the production of these new products. The only positive emissions are from the consumption of diesel fuel and the landfill of the inert material. Since the MBT plant is a net exporter of electricity, there are no emissions associated with the consumption of electricity. The overall GHG emissions, however, are expected to stay negative. Thus, it would be safe to conclude that the MBT plant plays a significant role in averting the GHG emissions associated with untreated MSW.

6. Conclusion

Bio-methanation of the organic fraction municipal solid waste to generate electricity is very much a feasible way forward for treatment of Indian MSW due to poor calorific value of waste and high organic and moisture levels in MSW. Besides such type (MBT based) of waste to energy plants use very little foot print area, are free from unhygienic conditions and leachate problems, which are commonly associated with only composting techniques used for Indian MSW treatment. MBT plant plays a significant role in averting the GHG emissions associated with untreated MSW. Overall, the study revealed an effective closed-loop waste management scenario for MSW valorization, which is environmentally friendly, economically feasible, and socially acceptable. It could help to achieve the vision of a circular economy.