A Critical Analysis on Anaerobic Digestion of OFMSW in India

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1 Introduction

Anaerobic digestion of OFMSW has turned into the most promising biochemical technologies in India because of the availability of higher moisture content of MSW [1]. AD is the most suitable practice for the treatment and minimization of municipal solid waste (MSW) towards waste to energy perspective for its biogas production after the end of the process. With intensifying requirements and quick diminution of fossil fuels, biomass is a suitable alternative for the fulfilment of energy demands at present in India [2]. The first AD in India was invented in the year of 1897 by Matunga Leper Asylum in Mumbai [3]. They used human waste as a feedstock of AD process with an idea to reduce their electricity need by producing gas. The first successful attempt was taken for AD in 1937 by S.V. Desai, a microbiologist of the Indian Agricultural Research Institute (IARI). India is one of the quick progressing nations with an even-increasing economy due to its rapid growth of populations. The amount of total municipal solid waste generated per day in India is 1,41,064 tonne as evaluated by [4] and mostly it encloses 40–60% of organic waste [5, 5]. It has been described that biogas production can be accomplished at the yield of 95 m^3/tonne of MSW with the help of AD [5] and the potential of this biogas for the MSW is evaluated as 9.23 Mm^3/day [6]. This biogas is having calorific value 20–25 MJ/kg and energy potential within a range of 5.5–8 kWh/m^3 [7–9]. According to numerous reports, 4 million animal waste biogas plants are installed in India [1], whereas 645 MSW biogas plants are fabricated as per [4] report. The Government of India has taken initiatives for the implementation of biogas plants and subsidies for rural areas. The preliminary study aims the AD reaction process, operating parameters with their optimum ranges and different digesters available in India [5]. The present study also emphasizes on the rector types with the current biogas model practices

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in India. Various literature surveys and reports were carried out to understand the current scenario of AD process for waste management in India. With an idea of the sustainability of current AD practices in India, this paper sincerely reviews the various AD models implicated in India and the accomplishments received by the different organizations under the Government of India so far. Not only does this research aim at the assessment of the AD process on the economic, social and environmental perspectives, these reviews and the data collections would be advantageous and instructive for policymakers, stakeholders, decisions makers for recommending new framework and policies.

2 Biochemical Reactions of Anaerobic Digestion

AD is a very intricate technique which contains a numerous number of complicated biochemical reactions under oxygen-free circumstances. The digestion basically a reduction process of biodegradable wastes with the help of microorganisms and the major by-product is CH_4 (50–75%) and CO_2 (25–50%) with a slight trace of H_2S and NH_3. The methane formation in AD associated with four different biological and chemical phases: hydrolysis, acidogenesis, acetogenesis, and methanogenesis are shown in Fig. 1 [10]. The overall biochemical conversion of organic waste for AD to CH_4, CO_2 and NH_3 can be represented as

$$C_aH_bO_cN_d + [(4a - b - 2c + 4d)/4]\, H_2O \\ \rightarrow [(4a - b - 2c - 3d)/8]\, CH_4 + [(4a - b - 2c + 3d)/8]\, CO_2 + dNH_3$$

where $C_aH_bO_cN_d$ signifies the complex organic matter of MSW [12]. A schematic diagram of anaerobic digestion process pathway, intricate solid organic waste degradation is described in Fig. 2. The first stage which involves during AD is hydrolysis or liquefaction where complex organic matter converts into soluble molecules with the help of hydrolytic bacteria [13]. Hydrolysis plays the role of rate controlling step in the overall process. It depends on the operational constraints such as pH, temperature, inhibition, substrate accessibility and bacterial population. In the second stage of AD, the organic matters including the monomers are transformed into volatile fatty acids (VFAs), acetic acids, H_2 and CO_2 by the digestion of acidogenic (fermentative) bacteria [14]. The third step is acetogenesis where monomers are assimilated by acetogenic bacteria to process CH_3COOH (acetic acid), CO_2 and H_2. At the final stage, methane is produced by methanogens and this methanogenesis step is a very complicated phase in the entire AD process because it is the slowest biochemical response of the system and very delicate to the temperature and pH of the substrate [11]. The non-digestible organic, mineral and residual material after the entire degradation process, consider as solid digestate.

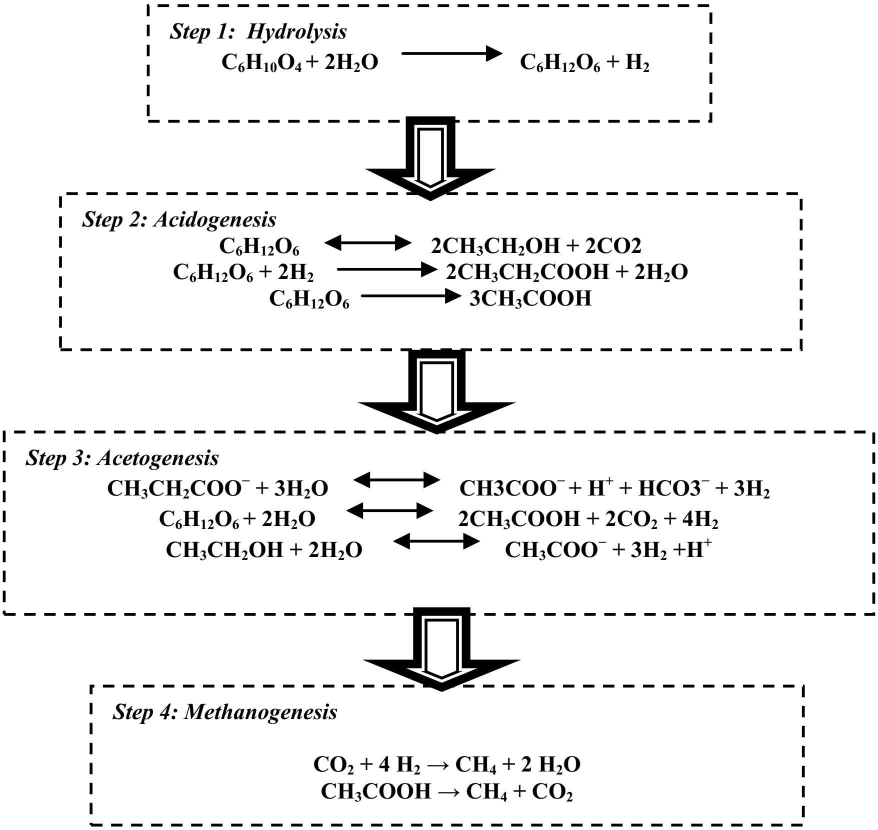

Fig. 1 Steps implicated in anaerobic oxidation of complex MSW [11]

3 Factors Affecting the Anaerobic Digestion Process for OFMSW

Depending on several process parameters, anaerobic digestion operates at an optimum circumstance for its highly sensitivity microorganisms which are implicated in methane production. Moisture content of raw OFMSW is appraised as one of the most essential factors affecting the waste stabilization. Higher amount of moisture content yields efficient biogas generation and it should be minimum 36% for a mesophilic digester with domestic vegetable waste fed [14]. The essential operating parameters of anaerobic digester like pH, temperature, volatile solids (VS), C/N ratio, hydraulic retention time (HRT), total solid content (TS) or organic loading rate (OLR), must be controlled within an optimum limit for the enhancement of the microbial activity which accelerate the process efficiency and biogas generation simultaneously [11]. The affecting process parameters for AD process of OFMSW with their optimum

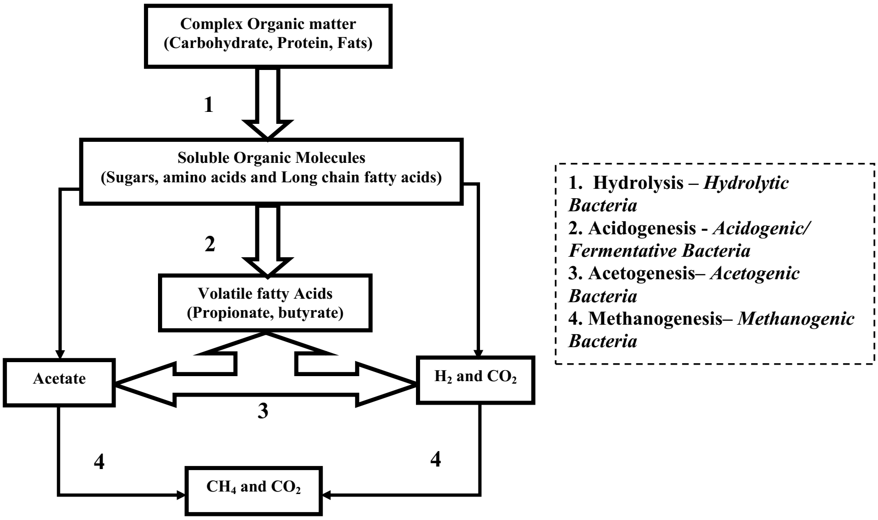

Fig. 2 Schematic diagram of anaerobic digestion process pathway [13]

Table 1 Operating process parameters and optimum conditions for AD process

Process parameters for anaerobic digestion					
Optimum range	pH	Temperature (°C)	C/N Ratio	Total solids content (TS)	Retention time (days)
	5.5–8.5 [11]	Mesophilic 25–40 °C Thermophilic 50–65 °C [8]	25–30 [16]	9.2 kg VS/m^3d [11]	Mesophilic 10–40 days Thermophilic 12–24 days [11, 8]

range are described in Table 1. The microbes are very sensitive to pH and temperature of the process specially the methanogenic bacteria [15, 16].

4 Existing Models of Anaerobic Digester in India

AD is one of the prime wastes to energy technology for emerging nations like India and biogas has become one of the essential renewable as well as sustainable energy sources which can be a substitution of fossil fuels. There are numerous different types of reactor technologies for AD processes and several different types of digester models are available in India [17]. AD process can be carried out into batch mode and continuous processes. In batch process, all four biochemical reaction phases of treatment process are executed in a single tank, whereas in continuous processes, it can be accomplished by continuous or semi-continuous loading, having a single stage or two-stage processes [18]. In conventional continuous AD process, all four biochemical stages are carried out in a single stage, wherein two-stage process organic wastes are decomposed first in hydrolysis–acidogenic stage reactor followed by the methanogenic reaction in upflow anaerobic sludge blanket (UASB) reactor which enhances the biodegradation efficiency [19]. The design of digesters may be diverged depending upon the waste composting, waste quantity and regional variations. Several types of models for biogas plants have been renowned in India by the Ministry of New Renewable Energy [20], Government of India, [21–23]. Two biogas digesters have been designed; one is the Chinese fixed dome digester having and the Indian floating cover biogas digester [24, 25]. The biodegradation process is identical for both reactors but the biogas collection process is much better in the case of Indian-type digester [25]. The Khadi and Village Industries Commission (KVIC) AD model is a floating dome type plant with a cylindrical digester made with steel model and very well known all over India [1], whereas Deenbandhu model, a fixed dome type plant with a hemisphere digester is rather cheaper than KVIC model. The Pragati model is also floating drum type plant having higher gas yield and it is a blend of both Deenbandhu and KVIC model with a hemisphere digester [21]. Tubular type digesters are fabricated with polyethylene tube-like bag with PVC gas collection pipeline but not applicable in case of high gas pressure system [1]. A numerous number of existing reactors and models of AD process in India have been described in Fig. 3 [1, 25].

5 Benchmark Practices of Anaerobic Digestion in India

Presently, in India, so many organizations, industries, agencies and research institutes are focused on waste management and minimization treatment process with an idea toward waste to energy recovery [2]. Anaerobic Digestion of OFMSW is one of the promising socio-economically and environmentally sustainable processes as per Indian context [6]. Ministry of New Renewable Energy (MNRE), Government of India has stepped forward to several initiatives for the implementation of both small- and large-scale biogas plants in both rural and urban areas [21]. Some private organizations like Indian Biogas Associations (IBA), Urban Local Bodies (ULBs), NGOs and Gram panchayats are also engaged for implementing biogas plants in public–private partnership (PPP) model in different possible locations in India for waste management and minimization and also for waste to energy recovery [1]. In conventional AD process, acidogenesis and methanogenesis stages are executed in a single reactor whether it may by floating dome type digester or fix dome type digester but now in the present scenario, two-stage AD process has become more efficient [9] because of the split-up of acidification and methanogenesis steps into two dissimilar reactors which expands solid handling capability and overall proficiency of AD as well as biogas production [23]. TERIs enhanced acidification and methanation (TEAM) process is an appropriate example of two-stage digestion and here methanation phase is followed up in an upflow anaerobic sludge blanket (UASB) reactor

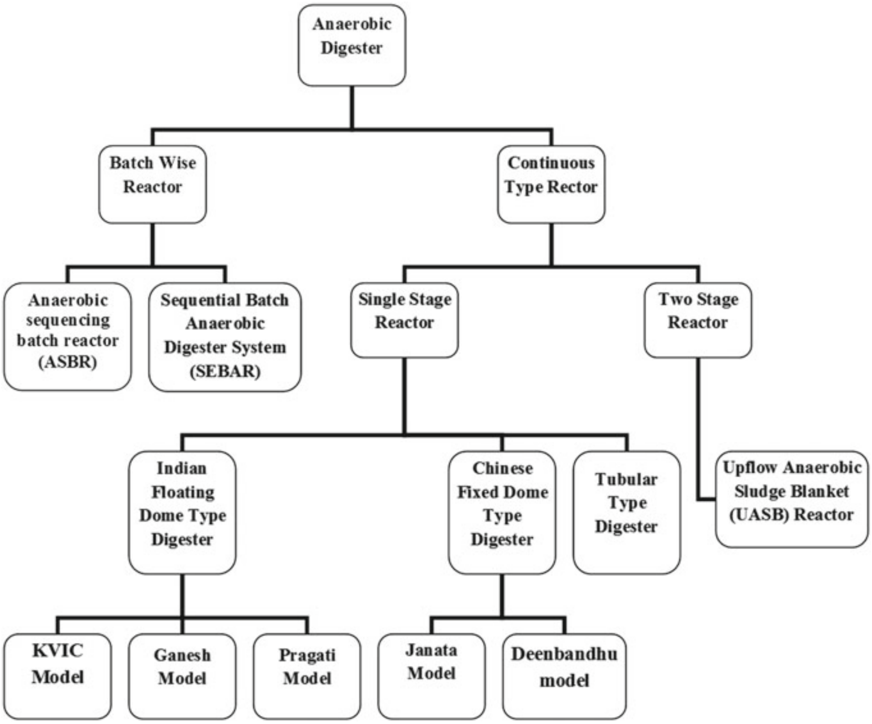

Fig. 3 Different existing reactors and models of AD process in India [1, 25]

[5]. A list of numerous success stories of biogas plants by AD in India is described in Table 2 [1].

6 Discussion and Recommendations

AD process for OFMSW management has developed various promising initiatives from the three piers of sustainability as well as waste to energy perspectives. From the environmental sustainability point of view, the practices of anaerobic digesters decrease the greenhouse gas emissions as well as reduce the global warming potential by effective utilization of waste resources. Waste to energy processes reduces the usages of woods, timbers which lead towards the diminution of deforestation to some extent. A few studies have been found on the environmental impact assessment of anaerobic digesters in India at present [1]. The global warming emanation in India, as well as other evolving nations, has been executed by reducing emanations by replacing conventional fuel sources [5], substituting of chemical fertilizers. 249 million tonnes of carbon dioxide emission can be mitigated in India by the encour-

Table 2 List of organizations using OFMSW from energy production in India

Sl No.	Organization	Feedstock	Process	Practices	Source
1.	TERI campus, Gurgaon	Food waste	Acidification and Methanation by UpFlow Anaerobic Sludge Blanket (UASB) reactor	Fuel and energy	Field visited by author
2.	KSRTC, Bangalore	Canteen wastes, food waste, OFMSW	Biomethanation	Cooking gas	Thomas et al. [1]
3.	Bellary municipality	OFMSW	Biogas through bio reactor	Power production	Thomas et al. [1]
4.	ASTRA, IISc, Bangalore	Green vegetables	Biogas through bio reactor	Fuel	Singh and Gu [26]
5.	Nisargruna Biogas plant, BARC, Mumbai	Kitchens waste, canteens waste, paper waste, green grass and leafy vegetables	two-stage anaerobic digestion	Organic manure and biogas as a fuel	Kakodkar et al. [27]
6.	Chamundi Hill, Mysore, Karnataka	Food waste	Anaerobic digestion in bio digester	Cooking Fuel	Field visited by author
7.	BBMP (Bruhat Bengaluru Mahanagara Palike)	Food waste and vegetable waste	Modified upflow anaerobic sludge blanket (UASB) process	Power generation	Ghosh et al. [5]

agement of AD [1]. Replacing biogas instead of fossil fuel diminishes the emission up to 60%, improving the air quality which is beneficial from the socio-economic perspectives. The anaerobic digesters can be a replacement of the fossil fuels and chemical fertilizer processes which minimize the expenses towards the acquisitions of conventional fuels and chemical manures for rural India. In the case of the Indian economy, 1 m^3 of biogas equivalents to 0.43 kg of LPG and nearly about Rs. 1821 can be retained per family by using biogas instead of LPG which becomes very favourable for lower income families. Presently, MNRE, Government of India is trying to implement anaerobic digesters all over rural India by imposing subsidies and instructions for operators and public awareness to consumers via different schemes.

7 Conclusion

In this study, a critical analysis of anaerobic digestion in India has been presented with special focus on reactor design and the process. The study found that a huge amount of OFMSW in India ends up in landfills which is the futility of the bioresources. Efficient policies from ministry and Government of India are solicited for effective utilization of this bioresource. Technologically, there are also scopes for improvement and innovations can increase reactor efficiency. Despite, the odds on the table more in-depth study on reactor design from the principles of chemical engineering and implementation efficient policy framework is required to ensure sustainability.

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