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RESEARCH ARTICLE

CURRENT STATUS AND FUTURE CHALLENGES OF TWO STAGE ANAEROBIC DIGESTION: A REVIEW

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ABSTRACT

Present investigation reveals the energy yield, environmental issues, and waste management through optimal two stage anaerobic digestion process. The various process parameters (TKN, pH, C/N ratio, moisture content etc.) need to control in such a manner that in less retention time, more biogas yield to be recorded with high quality manure. Present disposal of municipal solid waste (MSW) through incineration / landfills creates air, soil and ground water pollution. Presently, modern anaerobic digestion prefers two stage technology worlds- wide, because major environmental problems eliminated with the optimum biogas yield. The future challenges to be met are production of Bio H_2, Bio fuel, using various substrates along with MSW.

INTRODUCTION

Global population continues its exponential growth, so MSW management is becoming a major problem in the world. MSW is any discarded material generated from domestic, industrial, service sector, commercial even though agriculture and its processing sector etc. located in a city or town. The challenges surrounding MSW are going to be enormous, on a scale of, if not greater than, the challenges we are currently experiencing with climate change the report also spells out policy recommendations for reducing greenhouse gas emissions, many of which emanate from inefficient solid waste management practices. The constantly increasing demand for biogas as an environmentally friendly fuel implies an increasing demand for biogas plants to be efficient and to produce biogas with high methane content. In present time few methods used for disposal of MSW and generate energy. But two stage anaerobic digestions is the best technology for disposal of MSW and generate energy.

MSW potential in the world

In 2012, a global population of almost 7 billion [(1)] generated an estimated 1.3 billion tonnes/year to 2.2 billion tonnes / year MSW [(2)]. Population growth, urbanization, and rising standards of living are expected to drive this number higher, increasing global demand for energy. The amount of MSW is growing fastest in China (which surpassed the US as the world's largest waste generator in 2004), other parts of East Asia, and part of Eastern Europe and the Middle East. Growth rates for MSW in these areas are similar to their rates for urbanization and increases in GDP. There is a direct correlation between the per capita level of income in cities and the amount of waste per capita that is generated. Post-consumer waste is estimated to account for almost 5% of total global GHG, while methane from landfills represents 12% of total global methane emissions. MSW amounting to 140 billion tonnes globally may have an energy potential equivalent to 50 billion tonnes of oil. In terms of climate benefits, between 20-30 per cent of projected landfill methane emissions for 2030 can be reduced at negative cost and 30-50 per cent at costs of less than US\$ 20/tCO_2-eq/yr. As the population continues to grow, the increasing the amounts of waste generated started to become a problem, so the first dumps the established, usually being situated away from the human settlements [(3)] Uncontrolled dumpsites have been linked to many harmful health effects such as skin and eye infections, respiratory problems, vector-borne diseases like diarrhea, dysentery, typhoid, hepatitis, cholera, malaria and yellow fever. In the last 20 years, the amount of municipal solid waste disposed in our landfills has been substantially reduced due to recycling and composting - decreasing from 89% to 54%. Up until 1990, less than 15% of municipal solid waste was recovered. The organic fraction of the municipal waste sector contributes to about 5 per cent of the total GHG emissions known to be responsible for climate change. According to the Intergovernmental Panel on Climate Change post-consumer waste-generated GHG emissions were equivalent to approximately 1300 MtCO_2-eq in 2005.

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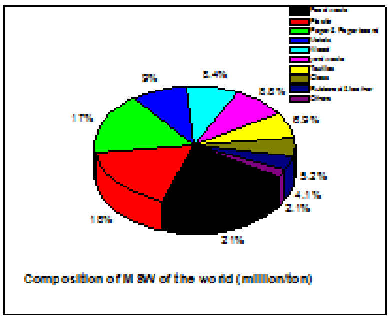
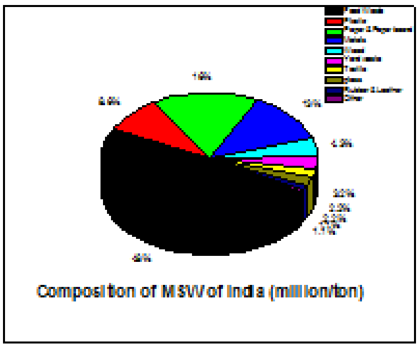
MSW potential in the India

Urban India generates 188,500 tpd tonnes per day (68.8 million tonnes per year) of municipal solid waste (MSW) at a per capita waste generation rate of 500 grams/person/day. The total waste generation figure is achieved by extrapolating the total tonnage of wastes documented for 366 cities (70% of India's urban population) India, with a population of over 1.21 billion account for 17.5% of the world population [(4)]. According to the provisional figures of Census of India 2011, 377 million people live in the urban areas of the country. This is 31.16 % of the Country's total population. Figure 3 illustrates that the growth of urban population is at a much faster rate than the growth of rural population. India has 475 Urban Agglomerations (UA), three of which has population over 10 million. Table 3 gives the top five UAs in terms of population. The very high rate of urbanization coupled with improper planning and poor financial condition has made MSW management in Indian cities an exceptional task. According to the research, if the trend continues, urban India will generate 160.5 million tpy (440,000 tpd) by 2041 and over the next decade some 920 million tonnes of MSW that needs to be properly managed. The study finds that the composition of urban MSW in India is 51% organics, 17.5% recyclables paper, plastic, metal, and glass) and 31% of inert (Jan. 2012 Waste-to- Energy Research and Technology Council.



Source: (CPCB, 2011)

Fig. 1. Composition of MSW of the world



Source: (CPCB, 2011)

Fig. 2. Composition of MSW of the world

Quantity & Characteristics of Indian Municipal Waste

Waste generated in 423 Class-I cities works out to 72.5% of the total waste generated each day and this needs to be treatment on priority. Municipal solid waste comprises 30% to 55% of bio-degradable (organic) matter, 40% to 55% inert matter and 5% to 15% recyclables. Composition of waste varies with size of city, season and income group.

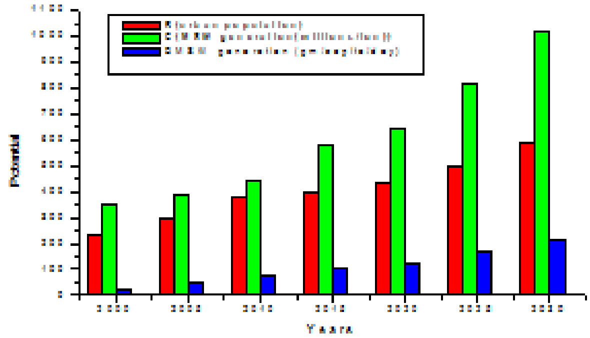


Fig. 3: Projected Municipal Waste Generations for urban population in India.(Source: Information from web site of CPCB)

Table 1. Population of Indian Urban city

Cities (UA)	Population (millions)
Greater Mumbai	18.4
Delhi	16.3
Kolkata	14.1
Chennai	8.7
Bangalore	8.5

Source: censusindia.gov.in/2011-Documents/UAs-Cities-Rv.ppt

Table 2. Per capita of MSW in Indian cities[(5)]

S. No.	Population	Waste generation rate Kg/capita/day
1	Cities with a population < 0.1 million (8 cities)	0.17-0.54
2	Cities with a population of 0.1-0.15 million (11 cities)	0.22-0.59
3	Cities with a population of 1-2 million (16 cities)	0.19-053
4	Cities with a population > 2 million (13 cities)	0.22-0.62

Table 3. Ten largest MSW producing cities in India

City	Population (millions)	Per capita waste (Kg./cap/day)	kiloton's/day
Delhi	1,03,86,926.219	0.57	5920
Mumbai	1,19,78,450	0.45	5320
Chennai	43,43,645	0.62	3035
Kolkata	4,57,876	0.58	2650
Hydrabad	36,37,483	0.57	2185
Bangalore	43,02,326	0.39	1670
Ahmedabad	35,20,085	0.37	1301
Pune	25,38,479	0.46	1172
Kanpur	25,51,337	0.43	1098
Surat	24,33,835	0.41	1000

Source: FICCI environmental conclave 2006, New Delhi
a. Population according to 2011census
b. Data acquired from local government

As compare to the western countries, MSW differs greatly with regard to the composition and hazardous nature, in India [(6&8)]. MSW composition at generation sources and collection point ,determined on a wet weight basis, consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). The C/N ratio ranges between 20 and 30, and the lower calorific value ranges between 800 and 1000 kcal/kg [(7)].

The current method of disposal

Rapid urbanization has led to over-stressing of urban infrastructure services including Municipal Solid Waste Management because of poor resources and inadequacies of the existing systems. In present time few method used for disposal of MSW and generate energy. Urban Local Bodies (ULBs) spend between Rs.500/- to Rs.1500/- per ton on solid waste management, of which 60% to 70% is spent on collection alone, 20% to 30% on transportation and less than 5% on treatment and disposal which is very essential to prevent environmental pollution. Organic fraction of municipal solid waste contains bio-degradable matter ranging from 30% to 55% which can be profitably converted into useful products like compost (organic manure), methane gas (used for cooking, heating. At least 50% to 55% of municipal solid waste is also a valuable resource which can be recovered profitably using different technologies through following processing options:

Composting

- i) Incineration
- ii) Gasification Technology
- iii) Refuse Derived Fuel (RFD) Plants
- iv) Landfilling
- v) Anaerobic digestion
  - a) Single stage anaerobic digestion
  - b) Two stage anaerobic digestion

Disadvantage and Environmental Impacts

(Source: Waste-to-Energy Research and Technology Council (WTERT, 2011)) [(9)]

i) Composting: The study found that the compost product from mixed wastes was of very low quality and contaminated by heavy metals (lead, Pb, and chromium, Cr) and used for agriculture, it would introduce 73,000 tonnes of heavy metals into agricultural soils. The study also found that the calorific value of some composting rejects is as high as 11.6 MJ/kg (2770 kcal/kg).

ii) Incineration: The study also found that in the city of Mumbai alone, the open burning of solid wastes and landfill fires emit nearly 22,000 tonnes per year of pollutants into the air. These pollutants include Carbon Monoxide (CO), Hydrocarbons (HC), Particulate Matter (PM), Nitrogen Oxides (NOx) and Sulfur Dioxide (SO_2) plus an estimated 10,000 total emission quantity (TEQ) grams of dioxins/furans. According to the research, since open burning happens at ground level, the resultant emissions enter the lower level breathing zone of the atmosphere, increasing direct exposure to humans.

iii) Gasification: The study found that the gasification technology also emits the some pollutants into the air. The process is cost-intensive and can be used for hazardous waste / bio-medical waste only.

iv) RDF: The calorific value of MSW Pellets through RDF is 7.5 MJ/kg (1,790 kcal/kg). That the calorific value of MSW in India is not suitable for energy generation. Operation of the thermal treatment systems involves not only higher cost, but also a relatively higher degree of expertise.

v) Landfills: Generally, MSW contains large fractions of organic matter which can be metabolized by microorganism. The decomposition of these wastes generates gases such as methane, carbon dioxide, vinyl chloride, and hydrogen sulfide which slowly seep into the air around the landfill. This impairs air quality in the immediate vicinity and, on a larger scale, contributes to the greenhouse effect and global warming. As a consequence, methane and carbon dioxide are the main terminal products resulting from the degradation of organic matter in an ecosystem. Both of them are important greenhouse gases. Methane contributes global warming potential of about 25 times greater than Carbon dioxide. The stability of landfills was one of the major geotechnical tasks in landfill design and operation and has been a problem for years. The low waste density of waste reduced the surface flow of rainwater and evaporation, resulting in a high rate of water infiltration. Besides, landfill leachate decreased the shear strength of waste by mobilizing pore water pressure and flow pressure. Finally, this could trigger the possibility of landfill failure and lead to landslides. Because biogas is being generated in landfill through anaerobic degradation, the risks of the possibility for landfill explosion could be anticipated especially in the absence of post monitoring and improper landfill gas collection system.

vi) Anaerobic digestion process: Anaerobic digestion or known as biomethanization is a biochemical degradation process that converts complex organic material into simpler constituents in a series of metabolic interactions of a wide range of microorganisms that catalyzes the process in the absence of oxygen. Segregated garbage undergoes anaerobic digestion producing methane gas and effluent sludge. Bio-gas production ranges from 50 M^3 – 100 M^3 / MT of wastes. The gas is utilized for heating applications / dual fuel engines / steam turbines for generation of power. Sludge after stabilization can be used as soil conditioner. Typically, between 40% and 60% of the organic matter present in the feedstock is converted to biogas. The remainder consists of a residue with appearance similar to peat which has some value as a soil conditioner and also, with some systems, liquid residue has a potential to be used as liquid fertilizer.

According to [(10)], the ultimate main product of this process is the production of methane (55-65%) and carbon dioxide gas (35-45%). In addition, minor quantities of nitrogen, Hydrogen, ammonia and hydrogen sulfide (usually less than 1% of the total gas volume) are also generated. Generally, anaerobic digestion process consists of four stages with four different types of microorganisms: hydrolysis (hydrolytic bacteria), acidogenesis (acidogenesis), acetogenesis (acetogenesis), and methanogenesis (methanogens) (Fox and Poland, 1994). Different designs and configuration have been developed throughout the world to suit different solid concentration and microbial activity. The system used to treat MSW anaerobically can be classified. Into following categories:-

a) Single stage digestion system

Single stage process have one reactor for both acidogenic and methanogenic phase. These can be low solid (LS) or high solid (HS) depending on total solid (TS) content in a reactor.

b) Two stage digestion process

The two stage process was introduced to improve the digestate by separating methanogenesis stage from hydrolysis, acidogenesis and acetogenesis stage so that each reaction could be close to optimum. Typical two reactors are used, the first for hydrolysis/liquefaction-acetogenesis and second reactor for methanogenesis.

Two stage versus single-stage digestion

There are available studies claimed that two-stage anaerobic digestion could provide great advantages over the single-stage digestion [11] stated the two-stage treatment is reportedly provides more rapid and more stable treatment. In practice, however, [12] cited that the two-stage digestion has not been able to substantiate its claimed advantage in the market place and the added benefits in increasing the rate of hydrolysis and methanization have not been proven. Two stage concept was first introduced by [13 - 14]. This two-phase system was first used for soluble substrates and liquid waste [15 - 16]. Then phase separation has been studied by digestion of solid vegetable waste at the 80's Three mainly advantages compare with single anaerobic digestion, including less detention time, higher gas conversion efficiency and higher methane concentration were proved in some studies [17].

Limitations of single stage AD

i) The pre-treatment involves removing of coarse particles and heavy contaminants. These pre-treatment steps cause a loss of 15 - 25 % VS, with corresponding decrease in biogas yield.
ii) The other technical problem is formation of a layer of heavier fractions at the bottom of the reactor and floating scum at the top. The bottom layer can damage the propellers while the top layer effected to mixing. This requires periodic removal of the floating scum and of the heavy fractions, thus causes lower biogas yield.
iii) The obtained digested sludge used as a fertilizer not totally moisture free, so large energy consumed for drying of this sludge before using.
iv) High consumption of water.
v) Higher energy consumption for heating large value.

Advantages of two stage anaerobic digestion

a. The digested loading with slurry form so not losses of Volatile solid.
b. The scum floating layer not forms in the upper side of the digester due to recirculation of liquid.
c. The obtained digested sludge totally moisture free and direct use for soil conditioner.
d. The waste water after digestion used for the agriculture growth.
e. Design flexibility.
f. More reliable for cellulose-poor kitchen waste.
g. Only reliable design (with biomass retention) for C/N < 20.
h. Less heavy metal in compost (when solids not methanogenized).

Current status of two stage anaerobic digestion in India

Anaerobic digestion of organic fraction of MSW (OFMSW) is commonly and successfully used in industrial countries, In some developing countries, such as china, India and Nepal this process is exclusively used in rural areas mainly for the treatment of animal feces [18]. In India, the compostable matter in the MSW is ranging from 30.84% to 56.57% in very big cities (The biogas potential from MSW is estimated as 9.23 mm/day in India.

Status of two stage anaerobic digestion plant developed in India

i) Valorga installed a 90,000 MT/y facility in Tahiti and was reported to be planning installation of a 55,000 MT/y plant in India, but the latter project has not been confirmed.
ii) An Israeli environmental services firm called Arrow Ecology has patented a novel MSW. Separation process coupled with a two-stage digester called ArrowBio, which Santa Barbara and Coachella Valley in California was considering adopting in the early 1990s. Arrow Ecology installed an 80,000 MT/y (88,000 tons/y) version of the facility in Tel Aviv in 2002 that produces 2-3 MW of electricity. Arrow Bio systems have also been scheduled to be built in Australia, Mexico, and Scotland.
iii) Kompogas installed a 20,000 MT/y (22,000 tons/y) facility in Martinique in 200524.
iv) EcoTec of Finland was reported to be planning installation of a 55,000 MT/y plant in India based on the WABIO design, but the project has not been confirmed.
v) Entec Biogas GmbH of Austria reported that they were planning to build a 150,000 MT/y (165,000 tons/y) BIMA digester with 5 MW electrical capacity to treat MSW from Lucknow, India25.
vi) The Energy and Resources institute (TERI), New Delhi has developed a high rate digester for biomethanation fibrous and semi-solid organic waste. TEAM biogas plant has been installed
in TERI campus and at other corporate units like NTPC India). TERI enhanced acidification and methanation (TEAM) process is primarily a two stage process.
vii) Existing BARC biogas plant in India (Muller, 2007) Location capacity date of commissioning utility of gas BARC, Mumbai 1 tpd 2001 kitchen anushaktinagar ,Mumbai 5 tpd 2002 kitchen BARC Hospital site 5 tpd 2003 Kitchen Govandi , Mumbai 5 tpd 2003 kitchen Govandi ,Mumbai 5tpd 2003 electricity deonar BARC has developed a biogas plant which is based on a floating dome design. it has a two stage continuous wet system .The biogas plant runs on kitchen waste that is pre-treated (mixed with hot water, heated by solar heating and pulped) and discontinuously fed to the thermophilic aerobic pre-digester.
viii) BIMA technology (Lucknow) having a capacity of 300 MT per day that stopped within 6 month ocommioning (Muller, 2007). Likewise a plant in Chenni has been closed as well. Another problem while implementing biogas plants is the mindset of the people expecting energy generation from so –low cost systems. They underestimate the robustness of biogas plants required for sustaining operation over 5 to 10 years.

Future application of two stage anaerobic digestion under research work

1) Hydrogen production: Two stage processes for MSW degradation.

2) Hydrolysis and microbial community analyses in two-stage anaerobic digestion of energy crops.
3) Super blue box recycling (SUBBOR) enhanced two-stage anaerobic digestion process for recycling municipal solid waste.
4) Two-stage anaerobic digestion of two-phase olive mill solid waste.
5) Comprehensive study on a two-stage anaerobic digestion process for the sequential production of hydrogen and methane from cost-effective molasses.
6) Two-stage anaerobic digestion enables heavy metal removal.
7) Production of biorefineries through two stage anaerobic digestion.
8) Biodiesel from algae challenges and prospects.

A bench scale study of fermentative hydrogen and methane production from food waste in integrated two-stage process.

Total energy generate through the two stage anaerobic digestion

Average MSW composition carry	=42% of organic matter
Approx. Biogas yield	= 0.4m^3/kg
MSW generate in India per day	= 188500 tons/day
Biogas yield per annume	= 188500000 x0.42x0.4
	= 31668000 m^3 (approx.)
The calorific value 1m^3 of biogas	= 38131 KJ
Total energy content	= 3166800x38131 KJ
	=1.20x10^{11} KJ (approx.)
As we know 1 kWh	= 3600 KJ
So, Total Approx. electrical energy in kWh	= 1.20x10^{11}/3600
	=33,542,569.67 units
If energy conversion efficiency	= 70%
So, Total Approx. electrical energy in kWh at 70% efficiency	=33,542,569.67x0.70
	=23,479,798.77 kWh
Revenue generated @ Rs. 5.00 per unit per annum	= 23,479,798.77 x 5
	= Rs. 117,398,993.8

From the above calculation we find the annual output as well as the profit earned by the use of this technique in India.

Conclusion

The study concluded that two decades of economic growth since 1990 has changed the composition of Indian wastes, and that the quantity of MSW generated is increasing rapidly due to increasing population and change in lifestyles. Land is scarce and public health and environmental resources are precious. The current solid waste management (SWM) crisis in India should be approached holistically - while planning for long term solutions, focus on the solving the present problems should be maintained. People related to waste management should work with efficient technology such as two stage anaerobic digestions for disposal of MSW and generate bio-energy, worthy manure and reduces the environmental pollution. Two stage bio digestion a possible way to increasing the organic loading rate and gas production of the digestion of high-biodegradable waste. Two stage wet system and solid bed system were the main types to conducted digestion based on the state of substrates. All of the two stage solid bed reactors studied before was conducted in batch system. Continuous system should be introduced into using multi-hydrolysis reactors combining with a gasification reactor, which will result in continuous operation, high organic loading, high biogas yield and stable system biogas production.

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