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International Journal of Current Research
Vol. 7, Issue, 03, pp.13749-13757, March, 2015

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

REVIEW ARTICLE

BIOMASS AS A SOURCE OF RENEWABLE ENERGY: A COMPREHENSIVE REVIEW

*,[1]Vishwas S. Patil and [2]Deshmukh Hanmantrao V.

[1]Lal Bahadur Shastri College of Arts, Science and Commerce, Satara (M.S.), India
[2]Department of Microbiology, Yashavantrao Chavan Institute of Science, Satara, M.S., India

ARTICLE INFO

Article History:
Received 16th December, 2014
Received in revised form
05th January, 2015
Accepted 23rd February, 2015
Published online 31st March, 2015

Key words:
Energy shortage,
Renewable energy,
Biomass,
Biomethanation, etc.

ABSTRACT

The world is facing energy crisis problem today. Reliable energy sources are thus necessary to meet the present energy needs. Most of the nations are dependent on non-renewable energy sources as fossil fuels and nuclear energy. These non-renewable energy sources have several limitations and disadvantages. The sustainable development of renewable energy alternatives offer many benefits both in socioeconomic and ecological principles. Biomass comprises any organic matter of either plant or animal origin. Biomass energy is the stored solar energy, carbon and hydrogen captured initially through photosynthesis into chemical bonds as organic matter. Biomass accounted for the largest share of renewable energy resources. Biomass is a vital source of energy for household and industrial energy requirements. Biomass has always been an important energy source for the country considering the benefits it offers. Thus, the purpose of the present review paper is to focus onto detailed aspects of biomass as a source of renewable energy.

INTRODUCTION

The economic, social and industrial growth of any country and civilization depends on energy. The commercial energy consumption is growing with the same pace of increasing population, high economic growth and industrial development. Energy is used for heating, cooking, transportation and manufacturing. Energy can be generally classified as non-renewable and renewable.

Non-renewable energy

Over 85% of the energy used in the world is from non-renewable sources. These sources are called non-renewable because they cannot be renewed or regenerated quickly enough to keep pace with their use. Most developed nations are dependent on non-renewable energy sources such as fossil fuels and nuclear power. At present, fossil fuels (oil, coal and natural gas) dominate the world energy economy, providing 80 per cent of the world's primary energy supply of 449 EJ/year (Heinimo, 2008). Estimates of the world's coal resources ranges from 6.9 X 10^6 to 11.8X 10^6 Mt. If consumption of coal for energy generation continues at the same rate, the current reserves will last for more than 200 years. The use of coal for energy generation has several environmental and social costs. The burning of coal results in atmospheric pollution due to release of sulfur dioxide, nitrogen oxides, heavy metals and carbon dioxide. The toxic ash remaining after coal burning is also an environmental concern and is usually disposed into landfills. Estimates of the world's oil resources ranges from 1450 to 2685 billions barrels and are likely to be consumed in next 20 years. Oil also causes environmental problems. The burning of oil releases atmospheric pollutants such as sulfur dioxide, nitrogen oxides, carbon dioxide and carbon monoxide. An oil spill accident kills marine organisms and birds. Estimates of the world's uranium resources ranges from 3.5 Mt to 6.6 Mt. These nuclear energy reserves would be adequate for running the present installed capacity of 350000 MW for a period of upto 35 years. The use of nuclear energy is much more expensive because of construction cost overruns, poor management and numerous regulations. This form of energy have disadvantage of safely disposing nuclear waste. Thus, it is now increasingly recognised that the sustainable path for energy development is necessary.

***Corresponding author: Vishwas S. Patil**
Lal Bahadur Shastri College of Arts, Science and Commerce, Satara (M.S.), India.

Renewable energy

The renewable energy alternatives offers many benefits such as less reliance on the earth's finite supply of fossil fuels, easy local availability, reduction of greenhouse gas emissions and environmental pollution. Many of these natural resources have a great potential for exploitation for energy generation. The complete perpetuity, easy local availability without any need for major transport, less green house gases release in environment, economy is independent of scale and its non-polluting nature are the advantages associated with renewable energy resources. The major renewable sources of energy are solar energy, wind energy, geothermal, hydropower and biomass.

Biomass as a source of renewable energy

Globally, biomass fuel contribute to 10– 14% of total energy requirements. Biomass fuels contributed 90% energy in the rural areas and over 40% in the cities. Biomass contributes over a third of primary energy. Biomass energy constitutes wood fuels, crop residues, animal dung, municipal and industrial solid wastes. Environmental concerns like global climate change, acid rain, air pollution from the use of fossil fuels and improvements in biomass technology have revived the interest in biomass energy as a renewable and sustainable energy source. The use of biomass along with other renewable energy sources can help to meet growing energy demands globally. When biomass is converted into electricity, heat, power, or transportation fuels, it is called biomass energy, or bioenergy. Biomass is a renewable energy resource because trees and plants can be grown, harvested, and re-grown in a short period of time. In addition, this process continually produces residues, wastes, and gases.

Biomethanation of biomass is of increasing interest in order to reduce the greenhouse gas emissions and to facilitate a sustainable development of energy supply. Biomethanation is the anaerobic digestion of biodegradable organic waste under controlled conditions of temperature, moisture and pH in an enclosed space to generate biogas comprising mainly methane and carbon dioxide (Naik *et al*., 2010; Lansing *et al*., 2008). Methane, a source of renewable energy can be used for replacement of fossil fuels in both heat and power generation and as a vehicle fuel (Petersen, 2008; Weiland, 2009). Another advantage includes energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities. Biomethanation of biomass is widely applicable and promising technology (Sinha and Pandey, 2011).

Advantages of biomass as energy source

The use of biomass as energy source has many advantages such as its abundance, reduced need for fossil fuels; biomass is always available and can be produced as a renewable resource; the use of waste materials reduce landfill disposal and makes more space for everything else; growing biomass crops produce oxygen and use up carbon dioxide; less import cost on foreign oil, can be easily converted into a concentrated, high energy fuels like alcohols or type of gas from is natural form with processing, and are cleaner burning than fossil fuels; less dependance on foreign oil; produces a smaller amount of harmful greenhouse gases than fossil fuel alternatives produce and; produces lower levels of sulfur dioxide which is a major component of acid rain, contain higher amounts of biodegradable organic matter suitable for biomethanation which is less capital investment as compared to other renewable energy sources (Amigun and Blottnitz, 2010).

Types of biomass amenable for biomethanation

Different plant biomass and waste has been widely studied for biogas production (Dubrovskis *et al*., 2009; Deaublein and Steinhauser, 2008). Organic waste is the main constituent of solid biomass and has a high potential for biogas generation but the uncontrolled decomposition of waste from agricultural and agro-industrial sources results in large scale contamination of land, water, and air. The use of waste biomass for renewable energy has several benefits. The use of agricultural waste becomes a brilliant spot among the whole alternative feedstock for biomethanation because it provides a path for rural development.

Biomethanation potential of vegetable waste

Vegetable waste represents a major share of agricultural wastes. Vegetable waste is produced in large quantities during harvesting, poor and inadequate transportation, storage facilities, marketing practices and processing of vegetables. Vegetable wastes are perishable and voluminous. Vegetable wastes contribute to a great amount of pollution.

Several studies have been reported on the biomethanation of mixture of vegetable waste by different researchers using anaerobic digesters of different designs and capacities under different operating conditions. Biomethanation of mixture of vegetable waste was studied several workers. Dhanalakshmi *et al*. (2012) used mixture of vegetable wastes for biomethanation using 2 L capacity single stage anaerobic reactor in mesophilic conditions at OLR- 0.25 and 0.5gVS/l.d, with the HRT of 25days, pH of reactor system 6.9-7.0. The biogas yield of 0.383 and 0.522 l/g TS added and 0.423 and 0.576 l/g VS added were observed for the two OLR respectively. Mondal and Biswas (2012) used green vegetables wastes and dried vegetable wastes for biomethanation using two identical anaerobic digesters run in batch mode at different temperatures and solid concentrations in slurry, pH 6.9. The biogas yield of 0.8 L/Kg DM/day was produced at 6% solids conc. Dried VW showed 11.0 L biogas /Kg at 10 d HRT and green VW showed 6.5 L biogas /Kg at 38 ^{o} C at 15 d HRT. Duran-Garcia *et al*. (2012) used peeling residues of potatoes, cabbage and carrots for biomethanation and estimated the volume of biogas being produced, substrate pH and substrate concentration, using different types of catalysts. Dhanalakshmi and Ramanujam (2012) studied vegetable waste biomethanation in 500 ml capacity bioreactor at mesophilic conditions, OLR in the range of 0.06 gm VS to 0.47 gm VS, pH of feed mixture 4.8 for 0.06 gm VS OLR. Maximum Cumulative gas produced- 3764 ml for 0.26 gm VS OLR. Velmurugan and Ramanujam (2011) studied biomethanation of vegetable wastes (Banana stem, Cabbage and Ladies finger) using 2 L fed-batch laboratory scale reactor under mesophilic conditions (35^{o}c), OLR was maintained at 2.25 g/l.d and HRT of 30 days, pH of VW slurry 5.75 and reactor residue avg pH 7.5. The biogas yield reported was 1.607 L/d. Babaee and Shayegan (2011) reported biogas yield 0.12-0.4 m^3/ (kg VS input) of vegetable waste. Liu *et al*. (2011) reported biogas yield 3.0 L /d to 3.5 L/d from vegetable waste biomethanation. Zhu *et al*. (2011) reported 660±20 mL biogas per g VS of vegetable waste added. Sunil Kumar *et al*. (2010) reported 0.15 m^3 biogas / kg of TS with a maximum gas production rate of 650 ml/h on day 25. COD reduction of vegetable waste slurry was approximately 65%. Selina and Joseph (2008) reported 0.391L biogas per g of VS fed. Kamaraj (2008) reported biogas yields 511.8 / kg COD des with a COD reduction of 75.6 % /kg VMW fed. Beatriz *et al*. (2013) studied co-digestion of vegetable processing wastes and livestock wastes using batch digester. In swine manure and vegetable processing waste co-digestions, CH_4 yield increased from 111 to 244 mL CH_4 g/VS added, and the percentage of VS removed increased from 50% to 86%. For poultry litter and vegetable processing waste co-digestions, CH_4 increased from 158 to 223 mL CH_4 g/VS added and from 70% to 92% VS removed. Many other scientists have studied vegetable and fruit waste biomethanation altogether.

Biomethanation potential of fruit waste

Fruit wastes are a source of nuisance in municipal landfills causing major environmental pollution problems. Current methods used to dispose fruit wastes are landfill and incineration but these methods releases methane, carbon dioxide and other pollutants that cause serious environmental and health risks (Qdais *et al*., 2010). Anaerobic digestion fruit wastes to generate energy have been carried out by several workers (Rajesh Banu *et al*., 2007; Cahyari and Putra, 2010; Narayani and Priya, 2012). Co-digestion of vegetable waste and fruit waste was studied by several researchers. Das and Mondal (2013) studied co-digestion of fruit and vegetable waste using 1 L batch digesters made of glass at HRT 15 days, temperature- 27°C,pH 5-7,TnO2 catalyst(0-1.5 gm/L conc.) Maximum yield of biogas was obtained with 4 % slurry concentration as 4.94 L/kg VS added. Earnest and Singh (2013) studied co-digestion of fruit and vegetable waste using 1.5L liters plastic bottles as digester at fruit waste, vegetable waste and cattle dung in different proportion 1:0.5, 1:1, 1:1.5, and 1:2, atmospheric temperature, 15days of digestion period. The biogas yield reported was 245 ml with 1:1 VW: CD ratio and 230 ml with 1:2 FW:CD ratio. Garcia-Pena *et al* (2011) studied co-digestion of Fruit and vegetable waste with meat residues in 30 L digester and biogas yield was found to be 0.25 (m^3/kg TS, removal of the organic matter (tCOD) was 65%. Bouallagui *et al* (2009) used fish waste, abattoir wastewater and waste activated sludge as co-substrates for the fruit and vegetable waste biomethanation using four anaerobic sequencing batch reactors at OLR of 2.46–2.51 g volatile solids (VS) l^{-1} d^{-1} and HRT 10 days. Sagagi *et al* (2009) studied co-digestion of Fruit and vegetable waste. Biogas yield for the cow dung (control) slurry with average production: 1554 cm3/wk, pineapple waste: 965 cm3/wk, orange waste: 612cm3/wk, lastly, pumpkin and spinach wastes: 373cm3/wk and 269cm3/wk respectively. Gunaseelan (2004) studied co-digestion of fruits and vegetable waste.

The co-digestion of fruit vegetable waste along with other easily available agricultural waste is also tried by several workers. Liu *et al* (2012) studied co-digestion of fruit–vegetable waste, food waste and dewatered sewage sludge using continuous stirred-tank reactor at OLR of 6.0 kgVS (m^3 d)$^{-1}$ and HRT of 20 d. The biogas yield was 4.25 m^3 (m^3 d^{-1}). Alvarez and Liden (2008) studied co-digestion of fruit-vegetable wastes, solid slaughterhouse waste and manure using 2 L reactors under mesophilic conditions and semi-continuous anaerobic process at OLRs in the range 0.3–1.3 kg VS m^{-3} d^{-1}. The methane content was 54–56% and its yield was 0.3 m^3 kg^{-1} VS added.

Other agricultural biomass used for biogas generation includes the wastes from agriculture based industries (Singh, 2007), plant residues (Ofoefule and Uzodinma, 2008), co-digestion of water hyacinth with primary sludge (Patil *et al*., 2011), wastes from aquatic growth, orange peel waste (Martin *et al*., 2010), co-digestion of orange peel waste and jatropha de-oiled cake (Periyasamy Elaiyaraju and Nagarajan Partha, 2012), co-digestion of cow dung with rice husk (Elijah *et al*., 2009) has been successfully attempted for biogas generation.

Biomethanation potential of animal wastes

Most of the cattle dung are disposed in landfills or are applied to the land without treatment. These inappropriate disposal methods can cause adverse environmental and health problems such as pathogen contamination, odour, air borne ammonia, green house gases, etc (Harikrishnan and Sung, 2003).

Anaerobic digestion of animal wastes (cattle manure) to generate biogas is reported by several workers. Asikong *et al*. (2013) studied cattle dung biomethanation at 15 days HRT. The biogas yield reported from cow dung without starter culture was 345mls, 640mls and 720mls and in the treatment with starter culture was 490mls, 640mls and 830mls respectively in 1kg, 2kg and 3kg weights within 15 days. The 1kg, 2kg and 3kg weights gave a total biogas yield of 2339mls, 3302mls and 4436mls with starter culture and 1141mls, 2650.50mls and 3750mls without starter culture respectively. Desai *et al*. (2013) used fixed dome type biogas plant for anerobic digestion of cattle dung. The biogas yield was 0.202 m3 /kg dry matter with 60% methane content. Abubakar and Ismail (2012) used lab scale 10L bioreactor working in batch and semi-continuous mode at 53^0C, OLR of up to 1.7 kg volatile solids (VS)/L d and an HRT of 10. The averaged cumulative biogas yield and methane content observed was 0.15 L/kg VS added and 47%, respectively. The TS, VS and COD removals amounted to 49%, 47% and 48.5%, respectively. Budiyono (2010) and Yusuf *et al*. (2011) also studied cattle dung biomethanation. The wastes of human origin (Khandelwal and Mahdi, 1989) also have good potential for biogas generation.

Co-digestion of cattle dung with other agro-industrial waste has been studied by several workers. Patil *et al.* (2013) studied co-digestion of cattle dung and water hyacinth using 250 ml batch digesters in temperature controlled thermo bath maintained at 35^0C, HRT 60 days. Biogas yield from water hyacinth was found to be 0.39 l/gVS which were 69.56% more in comparison with the control digester. Chellapandi and Uma (2012) studied co-digestion of cattle dung and Primary clarified bone waste (PCBW) from ossein factory in 2.4 L reactor at ambient condition. The biogas yield from PCBW (60%) with cattle dung (40%) reported appropriate for a maximum biogas production yield with 68-71% methane content. Biogas production yield (L biogas/ Kg TVS added) from CD only is 9.98±1.3 with 65±4TS % reduction (21.29±1.6 L/kg TVS added was produced for a mixture of 40% cattle dung and 60% PCBW). Muyiiya and Kasisira (2009) studied co-digestion of pig and cow dung mixture in proportions of 1:0, 3:1, 1:1, 1:3 and 0:1 using 1.5 L digesters. The maximum biogas yield was attained with mixtures in the proportions of 1:1. Shilpkar *et al.* (2009) studied co-digestion of cattle dung and Jatropha oil cake using 5 L capacity glass digesters fed with 6% total solids, HRT 180 days. The co-digestion of Cattle manure and Agricultural waste and energy crops Cavinato *et al*. (2010), Cattle excreta and Olive mill waste Goberna *et al*. (2010) have also been reported for efficient energy generation.

Biomethanation potential of kitchen waste

Current management practices for kitchen waste includes disposal in municipal landfill which causes the public health hazards and diseases. Inadequate management bears several adverse consequences. The potential of kitchen waste for biogas generation has been determined by several researchers. Lama *et al.* (2012) used modified ARTI model compact biogas plant of 1 m^3 digester for kitchen waste. The daily temperature inside the digester was found (25-34^{0}C) and pH value of the slurry was found to be 6.7-5.48. The average biogas production was found to be 173 L/day. Per kg of kitchen waste can produce 35 L of gas daily. Voegeli *et al.* (2009) studied kitchen waste biomethanation. The average daily gas production amounted to 290 L/d and 130 L/d when fed daily with 2 kg of food waste or market waste. TS reduction of 84.9% for food waste and 72.8% for market waste with feeding period with 2 kg/d. VS reduction 92.2% and 85.3% for food and market waste respectively with 42.5 days HRT. COD reduction was approximately 83%. Chen *et al.* (2008) used 15 m3 capacities two-phase anaerobic digestion pilot plant for kitchen waste biomethanation at OLR 250 kg kitchen waste, TVS 15%, warm water bath 35-37 ^oC, HRT 20 d. The biogas yield was 22m3/d, biogas conversion rate was 0.6 m3/ kg of VSS and VSS reduction was more than 80%. Kale and Mehetre (2006) used kitchen waste, dry leaves, green grass, animal remains and paper using aerobic and anaerobic digester at HRT 10-12 days. The biogas containing 70-75% methane was produced.

Co-digestion of kitchen waste with sewage water, sewage sludge and night soil sludge was successfully attempted separately for biomethanation (Subramani and Nallathambi, 2012).

Biomethanation potential of food waste

Food waste is major component of the waste stream of majority of cities.

Anaerobic digestion of food waste is studied for determining its biogas generation potential. Roati *et al.* (2012) used some food wastes for biomethanation and theoretical biogas yields equal to about 0.7-1.6 m3/kg VS containing methane contents equal to about 40-60% v/v were observed. Biswas *et al.* (2007) used food residues for biomethanation using 10 L capacity anaerobic digester in batch mode, optimum temperature of 40 °C and pH of 6.8. Kim *et al.* (2006) studied biomethanation of food waste using lab scale digester of 11L with working volume 8L. Biogas yield of 8.6L/day at 12 d HRT (CH4 content= 67.4% at 50 ^oC) was observed. The methane yield was 223 l CH4/kg sCOD degraded at HRT of 12 d. Food processing wastes are also found suitable substrates for biogas generation (Labatut *et al*., 2011; Banu *et al*., 2007), Food processing wastewaters generated from citrus processing, dairy processing, vegetable canning, potato processing, breweries, and sugar production (Sezun *et al*, 2011) also are good substrate for biomethanation. Liu *et al.* (2012) studied co-digestion of Food waste, fruit–vegetable waste and dewatered sewage sludge using continuous stirred-tank reactor at OLR of 6.0 kgVS $(m^3\ d)^{-1}$ and HRT of 20 d and biogas yield was found to be 4.25 m^3 $(m^3\ d^{-1})$.

Biomethanation potential of distillery industry waste

The distillery industries generate large volume of foul smelling coloured wastewater known as spentwash. In nearly all distilleries, about 12–15 liters of spent wash is generated per liter of alcohol produced. Approximately 40 billion litres of spentwash is generated per annum from 319 distilleries in the country (Kanimozhi and Vasudevan, 2010; Mohana *et al.,* 2009). The spent wash prevents penetration of sunlight into rivers and streams, thus reducing oxygenation of the water by photosynthesis and thus aquatic flora and fauna can adversely suffer. It results in eutrophication of contaminated water sources. Land disposal of distillery effluent can lead to groundwater contamination.

Biomethanation potential of spent wash has been determined by various researchers. Prakash *et al.* (2014) studied anaerobic digestion of distillery spent wash using wide mouthed Pyrex glass bottle of 5 liter capacity as reactor. The biological oxygen demand (BOD) removal was found to be 83.3-92.8 %. Amin and Vriens (2014) carried out anerobic digestion of distillation wastewater using UASB reactor made of polyvinyl chloride. The working volume of the reactor was 12 litres organic load of 24 g.l-1 of chemical oxygen demand (COD), a removal efficiency of up to 84% was achieved. Moreover, biogas was produced with a production rate of o.52 m3/Kg COD removed. Khairnar *et al.* (2013) reported that COD reduction goes on increasing the biogas production rate goes on increasing. Bozadzhiev *et al.* (2007) used laboratory-scale anaerobic baffled reactor with 2 L working volume for distillery wastewater biomethanation and biogas yield was found to be 1.7L/l.d with the 78% methane and 98% COD reduction.

Biomethanation potential of poultry industry waste

Poultry industry waste contains nutrient rich litter and manure which is used as an organic fertiliser in soils. However, over-application of this waste results in eutrophication of water bodies, the spread of pathogens (Oleskowicz-Popiel *et al*., 2009), the production of phytotoxic substances, high levels of NO_3 in drinking water can cause methaemoglobinaemia and cancer, air pollution and emission of greenhouse gases (Steinfeld *et al*., 2006). The biomethanation potential of poultry litter has been determined by several researchers. Karaalp *et al.* (2013) studied anaerobic digestion of chicken manure using 2 liter capacity continuously stirred tank reactor. The overall removal of total COD is 35-77%. Initially, biogas production rates were used to be between 0.5-1.5 m3/m3reactor/day. Rao *et al.* (2011) used self mixed anaerobic digester for the biomethanation of poultry litter at VS loading rate of 3.5 kg VS m^{-3} day^{-1} at HRT of 13 days. The gross VS reduction was 58%, gross methane yield was 0.16 m^3 kg^{-1} VS reduced. Singh *et al*. (2008) used 10 m3 fix dome bio-digester model for anaerobic digestion of Poultry waste at HRT 65 days and ambient temperature. The biogas yield reported was 3,000 L / day and 1,095m3/yr.

Co-digestion of poultry waste is advantageous. However, poultry manure produces more biogas than swine manure and cow dung (Ojolo *et al*., 2007) because of its high nitrogen content and high biodigestibility. The co-digestion of poultry waste is reported by several workers. Asikong *et al.* (2014) studied co-digestion of water hyacinth (WH), cow dung (CD) and poultry dropping(PD) by batch method under mesophilic temperature at HRT45 days. The water hyacinth-fed digester produced biogas (170.41mls) and poultry droppings-fed digester (182.88 mls). Combining all the substrates (WH+PD+CD) yielded the highest biogas (423.80 mls), followed by biogas production of cow dung (331.8 mls. The 3kg weight produced the highest biogas (364.40mls) 2kg (274.59mls) and 1kg yielded (192.68 mls). Babaee *et al.* (2013) studied co-digestion of poultry manure and wheat straw using pilot-scale digester with working volume of 70 L at Temp 25°C, 30°C and 35°C, OLR 1.0, 2.0, 2.5, 3.0, 3.5 and 4.0 kg Volatile solid/m3d and a HRT of 15 days. At 35°C, the methane yield was increased by 43% compared to 25°C. Anaerobic co-digestion appeared feasible with OLR 3.0 kg VS/m3d at 35°C. At this state, the specific methane yield was 0.12 m3/kg VS. The VS removal was 72%. Imam *et al.* (2013) studied co-digestion of, poultry waste, cow dung and water hyacinth using a model of batch type fixed dome biogas plant. The biogas yield from cow dung, poultry waste and water hyacinth was 0.034 m3/ kg, 0.058 m3/ kg and 0.014 m3/kg respectively. Poultry waste produced maximum gas 0.026m3 at the 8th day whereas cow dung and water hyacinth produced maximum gas 0.0263 m3 and 0.012m3 respectively at the 26th day. Nnabuchi *et al.* (2012) used a series batch digesters with 4.5 litre capacity each for co-digestion of chicken dropping and cow dung at HRT-30 days, ambient temperature (22-35), pH of chicken droppings-9.39. The maximum biogas yield was attained with mixtures in the proportions of 1:4(cumulative biogas level 2.7050L). The 100% chicken manure produced more gas per unit weight as compared to the 100% cow dung. Usman *et al.* (2011) studied co-digestion of domestic organic solid wastes and poultry droppings under mesophilic conditions using a laboratory-scale batch digester at HRT 20 days, temperature 40^0C. The average volumes of biogas generated in the setups were 40 and 44.45 ml day-1 respectively. This corresponded to 60 and 45 ml biogas (g l-1VS) in the respective digesters over the retention time.

Biomethanation potential of industrial waste

Anaerobic digestion of sugar mill press mud waste (Sanchez *et al*., 1996), Distillery industrial wastewater (Banu *et al*., 2007), paper-pulp industrial wastes (Ahn *et al*., 2002), cotton wastes (Isci *et al*., 2007), Dairy industry waste (Deshannavar *et al*., 2012), Barcelona's central food market organic wastes, fruit and vegetable processing wastes (Sumitradevi and Krishna Nand, 1989), Industrial wastewater have a potential for biogas generation (Fountoulakis *et al*., 2008), municipal wastewater treatment plants and of manure (Labatut *et al*., 2011), sewage sludge, residual sludge from wastewater treatment plants (Himanen *et al*., 2011) and municipal wastewater with residual sludge (Nakasaki, 2009).

Biomethanation potential of municipal solid waste

Several million tonnes of solid municipal waste is produced by households and institutions. The physico-chemical composition of municipal waste varies widely. Organic fraction of municipal solid waste (OFMSW) is the main component which is easily-biodegradable and consists of plant/animal kitchen waste; green waste; paper and cardboard, etc. Present management practice is the disposal in municipal landfills which bears several adverse consequences on environment and human health.

Anaerobic digestion to produce biogas from OFMSW has been studied by several workers.

Dasgupta and Mondal (2011) used 2 L capacity round bottom glass flask for anaerobic digestion of OFMSW and reported the biogas yield as 0.65 m3 / kg VS in presence of FeSO4 and alkali solubilised waste without any FeSO4 showed 0.45 m^3 biogas /kg VS. Ojolo *et al.* (2008) used batch-fed 200 dm^3 capacity anaerobic digester for biomethanation of vegetable component of municipal solid wastes. The biogas yield varied from 5.15 dm^3/kgTS to 5.83 dm^3/kgTS. Nguyen *et al.* (2007) studied biomethanation of organic fraction of municipal solid waste at OLR 0.8kg VS/m3.d and biogas yield was found to be 0.26m3/kg VS with 60 % methane content and 61% degradation of VS. Davidsson *et al.* (2007) used pilot scale reactors for biomethanation of OFMSW at HRT 15 days. The methane yield of 300–400 Nm^3 CH_4/ton VS_{in} corresponding to ~70% of the methane potential, VS-degradation rate ~80% were observed. Elango *et al*. (2006) studied co-digestion of municipal solid waste and domestic sewage using 5 L capacity batch type of reactor run in semi continuous mode with daily feeding. The biogas yield reported was 0.36m3/kg of VS added / day at the optimum organic feeding rate of 2.9 kg of VS/m3/day (with max reduction of TS (87.6%), VS (88.1%) and COD (89.3%) at the optimum OLR of 2.9 kg of VS/m3/day 68-72 %. Hartmann and Ahring (2005) studied thermophilic (55 °C) co-digestion of OFMSW: manure in ratio 50% (VS/VS) in reactor 2 for 6 wk; OFMSW to manure in ratio 100% in reactor 1 for 8 weeks at HRT 14–18 d and OLR 3.3–4.0 g-VS/l/d. The biogas yield reported was 0.63–0.71 l/g-VS. This yield is corresponding to 180–220 m^3 biogas per ton OFMSW. VS reduction of 69–74% was achieved with 100% OFMSW. Rao and Singh (2004) used 3.25 L capacity aspirator bottles for biomethanation of municipal garbage at HRT 100 days at room temperature (26 ±4 ^{o}C; average temperature 25^oC) and at ambient temperature (32± 10 ^{o}C; average temperature 29 ^{o}C) conditions for total solids conc. varying between 45 and 135 g/l. Biogas yield was 0.485-0.5 L/g VS added with methane content 62–72%.

Co-digestion of Municipal solid waste and fly ash (Lo *et al*., 2010), Municipal solid wastes and Fat, oil and grease waste from sewage treatment plants (Martin-Gonzalez *et al*., 2010) and Municipal solid waste and Slaughter house waste (Cuetos *et al*., 2008) was also reported.

Conclusion

Vegetable wastes and fruit wastes having high carbohydrate and moisture content are highly amenable for biogas production. Animal wastes have high organic matter and also crores of microorganisms that play an important role in biogas production. Kitchen waste, the organic material having high nutritive values is also suitable for biomethanation. The food waste includes uneaten food and food preparation leftovers from various residences, restaurants, school cafeteria, etc. These food wastes and wastewater from food industries are carbohydrate rich and thus are suitable for biomethanation. The biomethanation potential of distillery wastewater is related to its high BOD and COD value. Nutrient rich poultry industry wastes also have good potential for biogas generation. Industrial wastes also serve a good source for biomethanation. Renewable source of energy can be produced from carbohydrate rich easily biodegradable organic fraction of municipal solid waste.

Biomethanation of biomass alone or in combination with other agro-industrial wastes appears to be a potential economically viable option for the generation of renewable source of energy controlling environmental pollution. More research and advanced technologies should be developed to overcome the biomass disadvantages. The basic crops should be grown so that agricultural wastes will be available. There should be large scale production of biomass crops. The massive collection, harvesting and storage methods for biomass should be made inexpensive. The eco-friendly and safe exhaust gas cleaning technologies to biomass energy plants should be made economically feasible. Biomass conversion projects should be encouraged to reduce the costs of production of biomass based fuels for renewable energy generation.

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