ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 8, Issue, 12, pp.42842-42844, December, 2016

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

RESEARCH ARTICLE

SOLID WASTE ENERGY RECOVERY PROCESSES

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ARTICLE INFO

Article History:
Received 03rd September, 2016
Received in revised form
24th October, 2016
Accepted 16th November, 2016
Published online 30th December, 2016

Key words:

Energy recovery, Anaerobic digestion, Fermentation, Calorific value.

ABSTRACT

Municipal and Industrial solid wastes are considered to be a large quantity of organic fraction, a vital source of energy, which could be adopted for energy recovery by using coversion processes such as anaerobic digestion and fermentation. The net energy output in the form of methane and ethanol are calculated using chemical reactions of the above said processes. More potential is obtained from wastes subjected to the reaction of anaerobic digestion compared to fermentation. The calorific value of different organic wastes is found theoretically using a chemical formula. It indirectly gives the potential of the waste.

Citation: Sri Bala, G. 2016. "Solid waste energy recovery processes", *International Journal of Current Research*, 8, (12), 42842-42844.

INTRODUCTION

All human activities viz., domestic, commercial, industrial, healthcare and agricultural practices generate solid waste. The quantity and nature of the waste vary with the activity and with the level of technological development in a country. In the early days, before the advent of the industrial revolution, the major constituents of wastes were domestic sewage and agricultural residues, which were biodegradable in nature. But with the rapid urbanization, the problem of solid waste disposal has become a big problem. The quality of waste has changed i.e., to say non-biodegradable fraction has gained importance. If not managed properly, these wastes may impose many problems on the environment and public health arising from soil, water and air pollution. Many integrated energy conversion processes have been developed for proper utility of waste (National Solid Waste Association of India, 2005). The discarded materials are often reusable and may be considered as resource in another setting. Solid waste management is to maintain society's waste in a manner that meets public health and environmental concerns and public's desire to reuse and recycle waste materials. Solid waste management may be defined as the discipline associated with the generation, collection, storage, transfer, transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, aesthetics and environmental considerations (Techobanoglous *et al.*, 1993). Waste generation encompasses activities in which materials are identified as no longer being of value and are either thrown away or gathered for disposal. For example, the chocolate wrap once consumed is considered not important and is thrown out especially outdoors. The quantity of solid waste generation depends on factors such as standard of living, food habits and degree of commercial activities and the quality changes seasonally (Municipal Solid Waste Management manual, 2000). There is a large energy requirement due to rise in depletion of fossil fuels and also complications in energy recovery. Hence many energy conversion processes from waste have been developed but the energy from biomass is given more importance. Biomass is the name given to any recent organic matter that has been derived from plants as a result of photosynthetic activity. Biomass is chosen as an alternative because it is renewable, sustainable, environmentally friendly, abundant, untapped energy and by-products with no or less profit generated from agricultural and industrial processes. Biomass is also unique in nature since it is effectively stored solar energy and is the only renewable source of carbon and can be processed into solid, liquid and gaseous fuels (Twidell, 1998).

Basic biomass conversion technologies are:

(a) Anaerobic digestion: The process of breaking down the organic materials in the absence of air with the help of bacteria to intermediates such as alcohols and fatty

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acids and finally to methane, carbon dioxide and water (Mital, 1996).

(b) Fermentation: Ethanol can be produced from certain biomass materials that contain sugars, starch or cellulose. The best-known feedstock for ethanol production is sugar cane, but the other materials can be used. Starch based biomass is usually cheaper than sugar-based materials, but requires additional processing (Rittman & McCarty, 2000).

Apart from this, there are other conversion technologies such as pyrolysis, gasification, charcoal production, co-firing, briquetting and pelletising, combustion and co-generation. In this study, energy is calculated for different wastes using the reactions of anaerobic digestion and fermentation reactions. The other processes are not considered. In order to make the results and analysis as transparent as possible, the calculations are made for individual wastes more clearly.

MATERIALS AND METHODS

Anaerobic Digestion

The amount of biogas produced for each individual organic waste is found out using the equation of anaerobic digestion. During anaerobic digestion, a chemical oxygen demand (COD) balance can be used to account for changes in COD. Instead of oxygen accounting for the change in COD, the COD loss in the reactor is accounted for methane production. By stoichiometry, the COD equivalent of methane can be determined. The COD of methane is the amount of oxygen needed to oxidize methane to CO_2 and water.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

From the above equation, the COD per mole of methane = 64 g O_2 $mole^{-1}$ CH_4

The volume of methane per mole at standard conditions (0°C and 1atm) is 22.414 L, so the methane equivalent of COD converted under anaerobic conditions is 0.35 L CH4 g^{-1} COD. The quantity of methane at other than standard conditions is determined by using the universal gas law to determine the volume of gas occupied by one mole of CH_4 at the temperature in question.

$$V = (nRT)/P\text{-}1$$

Where
V= volume occupied by the gas, L
n = number of moles
R = universal gas law constant, 0.082057atm. L $(mol.K)^{-1}$
T = temperature, K (273.15+°C)
P = absolute pressure, atm

Thus at 35°C, the volume occupied by one mole of methane is 25.29 L. Because the COD of one mole of methane is equal to 64 g, the amount of methane produced per unit of COD converted under anaerobic conditions at 35°C is equal to 0.40 L. Thus anaerobic digestion is represented by means of the following equation is given by Peavy & Rowe.

$$CaHbOcNd + (4a - b - 2c+3d)/4H_2O \rightarrow (4a+b-2c-3d)/8\ CH_4 + (4a-b+2c+3d)/8\ CO_2 + d\ NH_3$$

Where C,H,O,N represent the elements of organic fraction in the above equation [1].

The elemental composition of the waste is given as weight percentage, the formula is to be derived by using chemical stoichiometry. Some halogenated constituents such as sulphur inhibit the formation of biogas to some extent. The amount of inhibition is represented by means of an inhibition factor. The following equation is used if the sulphur content is present in the waste.

$$CaHbOcNdSe + (a\text{-}b/4+c/2+3d/4+e/2)\ H_2O \rightarrow (a/2 +b/8+c/4+3d/8+e/4)\ CH_4 + (a/2\text{-}\ b/8+c/4+3d/8+e/4)CO_2 + d\ NH_3 + eH_2S$$

For the calculations, 1 Kg of substrate is taken into account (Metcalf & Eddy, 2003).

Fermentation

In any biological treatment, organic matter acts as an electron donor in energy metabolism. However it is not so in all the cases i.e., in fermentation reaction, one part of the organic compound is oxidized and another part is reduced. For example, some of the carbon in glucose can be oxidized to carbon dioxide, while the other carbons are reduced to ethanol (Rittman & Mc Carty, 2000). In the fermentation process, half reaction stoichiometry is involved. Clubbing two half reactions, a final reaction for fermentation is achieved wherein ethanol is an important by-product. One of the custom organic half-reaction is represented as follows:

$$(n\text{-}c)/d\ CO_2 + c/d\ NH_4 + c/d\ HCO_3 + H^+ + e^- \rightarrow 1/d\ CnHaObNc + (2n\text{-}b+c)/d\ H_2O$$

In the above said equation, organic matter is represented by CnHaObNc. Similarly there will be other organic half- reaction which is as follows:

$$1/6\ CO_2 + H + e^- \rightarrow ½\ CH_3CH_2Oh + ¼\ H_2O$$

Using the above two reactions and balancing them we get the amount of ethanol. The ethanol is in Kg per 1 Kg of substrate. The calorific value of ethanol is 30 KJ/g. Using stoichiometry, the energy in KWH is obtained. The chemical composition is known from literature and the formula is derived using stoichiometry.

Calorific value

The calorific value gives the energy potential of a solid or liquid fuel. The calorific value of solid or liquid fuel is generally determined by using the bomb calorimeter. Dulong has developed a formula for the theoretical determination of the calorific value. The calorific value can be approximately computed by noting the constituents of the organic compound. The calorific value is measured in Kcal/Kg. The formula for measuring the gross calorific value (Higher calorific value) is

$$HCV = 1/100\ [8{,}080C + 34{,}500(H - O/8) + 2{,}240S]\ Kcal/Kg$$

The net or east calorific value (NC V) is measured using the formula.

$$LCV = [HCV - 0.09H \times 587]\ Kcal/Kg$$

Where C,H,O,S represent the elements carbon, hydrogen, oxygen and sulphur of the fuel. Here the fuel is nothing but the organic waste (Jain & Jain, 2003).

COD reduction

In any biological treatment of wastes say anaerobic digestion, the efficiency of the process depends on the COD reduction. To evaluate the energy balance and energy efficiency in biogas systems based on various substrates, an energy input/output ratio was defined. The energy efficiency is nothing but the sum of primary energy input into the system (anaerobic digestion) divided by energy content in the biogas produced. The higher the ratio, the less energy efficient is the system (anaerobic digestion). When the ratio exceeds 100%, the energy, the energy balance turns negative (Maria Berglund, Pal Borjesson, 2006). COD reduction efficiency is indirectly related to the gas production in an anaerobic system. Only a part of the biogas formed in the system is available for energy purposes, the rest staying dissolved in the wastewater and passing out with the effluent. In terms of COD balance, about 80% of the COD is removed in the process, while the balance goes out with the effluent. Relatively, small percentage of COD is consumed in sulphate reduction (Bal & Dhagat, 2001).

RESULTS AND DISCUSSION

As an initial step the data about the organic fraction of different wastes is known. Since the chemical composition of the waste is known from the literature, the chemical formula is derived as per the stoichiometry. Energy output from the wastes in KWH using the reactions of anaerobic digestion and fermentation were calculated and presented in Table 1 as shown below:

Type of waste	Chemical Formula	Anaerobic digestion (KWH)	Fermentation (KWH)
OFMSW	$C_6H_{10}O_4$	4.906	5.237
Textile	$C_{31}H_{49}O_{19}N$	4.97	0.525
Rubber	$C_{24}H_{26}N$	10.15	11.601
Paper	$C_{72}H_{96}O_{30}N$	8.51	7.055
Tannery	$C_7H_{11}ON$	7.583	8.697
Fruit	$C_{32}H_{48}O_{19}N$	5.02	0.125
Food	$C_{31}H_{49}O_{18}N$	5.16	0.125
Meat	$C_{39}H_{51}O_{10}N$	7.37	8.489

The calorific value is determined for the different wastes using the mentioned formulae. The values are presented in Table 2.

Type of waste	HCV(Kcal/Kg)	LCV(Kcal/kg)
Rubber	9301.86	8905.64
Paper	4892.38	4591.25
Tannery	7116.71	6694.07
Textile	4365.88	4027.768
Meat	6997.97	6501.37
Fruit	4358.84	4031.3
Food	4473.86	4135.75

The main aim of the study was to analyse the energy performance in biogas production is affected by the raw materials digested. Consequently the results are useful to identify the factors affecting the energy output and as a guideline for future assessments, rather than to rank or give exact figures on the net energy output from different existing, or potential, biogas systems. However it is difficult to draw any general conclusions on the energy output from different wastewater streams since it is not only affected by the raw materials but also on the different reactor configurations for different waste water streams. There are large variations among the raw materials studied regarding origin and the potential for energy contribution. In case of handling the raw materials, there are important differences between energy crops and waste products from industrial and municipal sectors. The reactions of anaerobic digestion assume 100% efficiency but not the same in real conditions.

Conclusion

The overall conclusions of the energy system analysis are:

- The net energy output from the processes of anaerobic digestion and fermentation depends on the composition of the waste and the limitations of the concerned equation
- The calorific value for the organic waste found theoretically roughly gives the energy potential

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