Renewable and Sustainable Energy Reviews 80 (2017) 756–764

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Optimising biogas production from anaerobic co-digestion of chicken manure and organic fraction of municipal solid waste

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ARTICLE INFO

Keywords:
Anaerobic
Biogas
Co-digestion
Micronutrients
Mono-digestion
OFMSW

ABSTRACT

In this study, it was observed that in experimental work under laboratory scale using conventional biochemical methane potential (BMP) assay, the loading rate ratio 4:1 had optimum biodegradability rate than other ratios which were investigated, while the loading rate ratio of 1:1 had optimum biogas and methane yield after 15 days hydraulic retention time. It was concluded that chicken waste (CM) mono-digestion has higher biodegradability rate compare to organic fraction municipality solid waste (OFMSW) mono-digestion. Co-digestion of OFMSW and CM stabilizes conditions in digestion process such as carbon to nitrogen (C:N) ratio in the substrate mixtures as well as macro and micronutrients, pH, inhibitors or toxic compounds, dry matter and thus increasing biogas production. It was concluded that the organic waste generated in the municipal landfills could be co-digested with CM to produce methane which can be used as a source of environmentally friendly and clean energy for the transport sector, industries and residential homes.

1. Introduction

THE economics development of African countries depends on power generation and use. With the fast depletion of non-renewable energy sources such as coal and fossil fuel which has led to environmental degradation, human health problems and global climate change [1,2]. The commercial production of bioenergy and other alternative energy sources such as solar energy, wind energy, hydropower, geothermal will definitely give a drive for the development of the economy [1–3]. Energy efficiency is dependent on the thermal insulation properties, quality and structure of the construction. The continuous in prices for heating, electricity and operational expenses gives increased interest in the use of renewable energy sources and development of energy efficiency methods (models). It important not only to be able to produce cheap and clean renewable source but also to take into account the climate change and optimise the use [4]. According to Esen et al. [5] the interest in an alternative or renewable energy sources for greenhouse heating is currently high, due to relatively high prices of fossil fuels and heating loading. This gives alternative sources of energy like biogas, solar, and ground sources heat pump greenhouse heating systems (BSGSHPGHS). These study demonstrated that some renewable energy source such as biogas, solar and ground energy can efficiently heat greenhouses during winter [5]. According to Cuce et al. [6] on the analysis of total energy consumption; energy efficient are environmentally friendly technologies. Renewable energy technologies are widely considered to reduce world energy consumption that dominates fossil fuels and mitigate greenhouse gas emissions in the atmosphere through clean energy generation. This reduces operational costs and ultimately carbon emissions. Thus, reducing the dependency of the grids [6]. According to Behera et al. [7] on the study of factors determining the household use of clean and renewable energy sources for lighting in Sub-Saharan Africa using data from Living Standards Measurements Study (LSMS). Its shows people who still live in the rural area depend on kerosene, solid fuel, batteries for lighting while a just small fraction of the population uses renewable energy such as solar, bioenergy [7]. Renewable energy system such as solar photovoltaic, solar thermal, geothermal and wind technologies are currently used in water treatment such as desalination systems according to Al-Karaghouli et al. [8]. Energy cost, maintenance cost, capital investment and operational cost are the main contributors to the water production process. Energy cost contributes 50% of the water production cost. Using renewable energy sources assists in lowering the energy cost and at the same time saving the environment [8]. The objective of the study was to look into the benefits and pitfalls encountered when co-digestion is employed while selecting a high yield co-digesting substrate for use in an anaerobic digester. The study focused on the following objectives:

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http://dx.doi.org/10.1016/j.rser.2017.05.068
Received 9 March 2016; Received in revised form 15 February 2017; Accepted 16 May 2017
1364-0321/

2. Determine the effect of mono-digestion and co-digestion of CM and OFMSW on biogas and methane production in an anaerobic digester.
3. Optimise the efficiency of biogas and methane production of CM and OFMSW by looking into process parameters such as; organic loading rate (ratios).

1.1. Biogas production

Biogas is used in the form of fuel, heat and electricity. It is desirable to create a worldwide energy friendly system which is sustainable and with zero carbon emissions. This results in resource conservation and environmental protection [9,10]. In cogeneration units (combined heat and power (CHP) biogas which is dried and sulphur free can be used to produce heat and electricity [11]. It can be further upgraded to biomethane by concentrating methane in biogas. This is achieved by washing with water, membrane separation technology, amine gas treating, pressure swing adsorption and selexol adsorption to remove the CO_2 and H_2S in biogas. Bio-methane retains similar characteristics as natural gas. Therefore, it can be used in gas engines and vehicle fuels since it can be stored the same way as natural gases. As more applications of biogas are being discovered, it can also be used to substitute carbon in plastic production. In Europe and its state of the Soviet Union, it has been estimated that bio-methane production by the year 2020 they will achieve 250 billion standard cubic meters (m^3N) of bio-methane which will be sufficient to cover half of the current consumption. Biogas is produced in an anaerobic digester using mono-digestion or co-digestion. Co-digestion favours high yield of methane due to the availability of varies vital trace elements contributed by the different substrate. In mono-digestion, these essential trace elements are insufficient [11].

Biogas is composed of gases such as methane, carbon dioxide, hydrogen, carbon monoxide, hydrogen sulphide, ammonia and a trace amount of oxygen. It is produced by the breakdown of biodegradable organic materials using bacteria under controlled conditions. These include municipal solid waste, agricultural waste, industrial waste and animal waste [12,13]. When the process is operated at optimum conditions the ratio of CH_4 to CO_2 is approximate 60:40 [14]. Biogas is a source of bioenergy. In satisfactory amount and standard can be utilised for electricity or heating [14]. In combustion, methane is converted into bioenergy, therefore, it is not released to the surroundings. However, CO_2 is released in small amounts that do not affect the atmosphere compare to that of CH_4 and nitrous oxide N_2O when they are in the atmosphere [14]. In a case where CH_4 and N_2O are in the atmosphere, they have a great impact due to their greater ability to trap energy compared to CO_2 [14].

Biogas production takes place in series of four biochemical fundamentals steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis [15]. Fig. 1 shows biochemical steps of the anaerobic digestion process. Hydrolysis is the first step of the biogas decomposition process. This step involves the breaking down of large organic polymer chain into smaller molecules.

During this phase, carbohydrates are broken down into simple sugars, protein into amino acids and fats into long fatty acids [18]. While some of the products of hydrolysis including acetate and hydrogen may be used by methanogens in the last stage in the anaerobic digestion (AD) process [19]. The products of hydrolysis then undergo the next step in AD known as acidogenesis in which acidogenic microorganisms further break down the substrates. These fermentative bacteria produce an acidic environment in the digestion media while creating ammonia (NH_3), hydrogen (H_2), carbon dioxide (CO_2), hydrogen sulphide (H_2S), shorter volatile fatty acids, organic acid (acetic, butyric acid, propionic acid, lactic acid etc.), and low alcohols are produced [19]. During acetogenesis step, a derivative of acetic acid known as acetate is created from carbon and energy sources by acetogens. This is a very important step in the AD that requires close cooperation between the organisms that carry out oxidation and the methane-producing organisms that are active in the next stage of actual formation of methane [18]. This process constantly utilizes hydrogen gas thus keeping the concentration of hydrogen gas at a sufficiently low level. Methanogenesis is the final stage of AD in which methanogens create methane from the final products of acetogenesis (i.e. carbon dioxide, hydrogen gas and acetate) as well as from some of the intermediate products from hydrolysis and acidogenesis [20]. In this stage, carbon dioxide and methane (biogas) are formed by various methane-producing microorganisms called methanogens [16,18,19]. Eq. (1) shows a simplified generic anaerobic digestion [21].

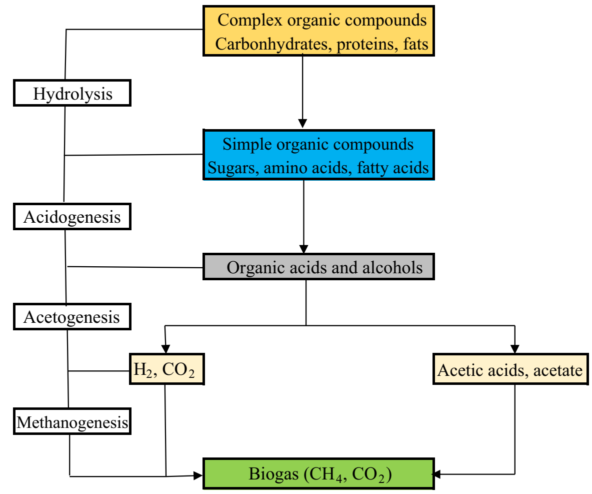

Fig. 1. Biochemical steps of anaerobic digestion process [16,17].

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad (1)$$

1.1.1. Conditions of anaerobic digestion

The rate of biogas production depends on a number of conditions (parameters) that include; hydraulic retention time, temperature, C/N ratio, organic loading rate, partial pressure, pH, nature of the substrate, microbes balance, and Oxygen exposure to anaerobic [22–25].

1.2. Temperature

To operate at the optimum temperature, it is important to consider the type of microorganism present and the conditions they survive in. Microorganisms are classified in terms of the temperature range in which their growth accelerates [26]. Temperature classification of the microorganisms is psychrophilic, mesophilic and thermophilic.

- Psychrophilic optimum operating temperature range is < 10 °C.
- Mesophilic is within 20–45 °C and optimum temperature is 35 °C.
- Thermophilic optimum temperature is > 50 °C, normally the operating optimum temperature range is 55 °C. An anaerobic digester operating at thermophilic condition is mostly unstable and has high energy intake although it produces a high percent of the biogas.

1.3. pH

The AD process is greatly affected by variation in levels of pH. Microbes cannot grow under high acidic conditions, hence anaerobic digester failure or low methane yield occurs. Optimization of digestion pH is preferred to be ranging from 6 to 7 [27,28]. The first stage produces volatile fatty acids which lower the pH due to the chemical interaction of CO_2 and water (H_2O). Hydrogen carbonate ions are formed and restore stability. See Eqs. (2) and (3).

$$CO_2 + H_2O = H_2CO^{3-} = H^+ + HCO^{3-} \quad (2)$$