Chapter

Introductory Chapter: An Overview of Biogas

J. Rajesh Banu and R. Yukesh Kannah

1. Introduction

According to the International Energy Agency Report 2018, the global energy demands (GED) elevated 2.1% from the previous year. However, 70% of GED was met through oil, coal and fossil fuel. Among these, fossil fuel accounts for 81% of total energy demand (TED). The percentage of fossil fuel remains unchanged for the past three decades. Exploitation of fossil fuel extended the emission of carbon dioxide (CO_2) to 32.5 GT (gigatonnes) in the year 2017. Surplus emission of greenhouse gases (GHG) into the atmosphere is the major contributor for global warming and climate change. On considering, the profile of GHG emission researchers comes out with innovative ideas to minimize the emission. Nowadays, researchers and policymakers are working together to recognize alternative energy source to encounter the energy demand and global warming impacts.

Anaerobic digestion (AD) process is the cost-effective and emerging technology to derive biogas from various liquids and solid wastes. AD process is more suitable for valorization of high-strength organic waste under both mesophilic (30–40°C) and thermophilic (50–60°C) conditions. AD process is otherwise termed as biomethanation or biochemical degradation. AD process is a more environmental-friendly, energy-yielding and more efficient bioenergy production method than other waste processing technologies.

AD process dominant by anaerobic microbes, which plays major role in conversion of organic rich waste biomass into two valuable products such as methane and nutrient rich digested/effluent. Anaerobic breakdown of complex organic waste biomass follows four major steps, and these are (i) hydrolysis, (ii) acidogenesis, (iii) acetogenesis and (iv) methanogenesis. **Figure 1** represents the pathway of anaerobic degradation of organic waste.

Among them, hydrolysis is the rate-limiting and first step of AD process. During hydrolysis, complex organics ($C_6H_{10}O_4$) such as protein, carbohydrate and fat are converted into simple digestible amino acids, monosaccharides and fatty acids. Eq. (1) shows that the reaction occurs during hydrolysis phase; enzymes convert the complex organic substrate into simple monomers ($C_6H_{12}O_6$) and hydrogen (H_2) as shown below:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + H_2 \quad (1)$$

Hydrolysis is a very slow process when compared with other steps involved in AD process. Inadequate hydrolysis of organic waste affects the efficiency of AD. In order to increase the rate of hydrolysis, many researchers have adopted various pretreatment methods. Banu and Kavitha [1] have reviewed in detail regarding various pretreatment methods and their effects on anaerobic digestion.

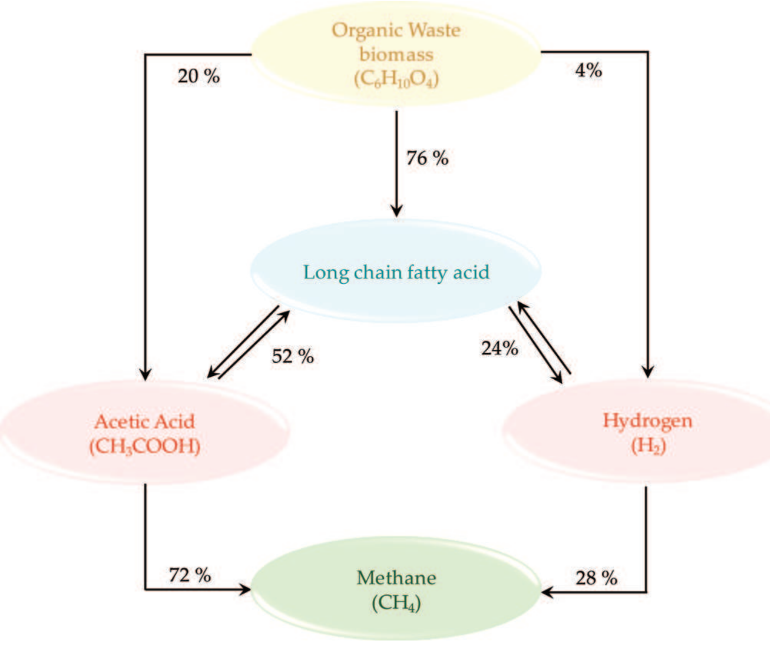

Figure 1.
Pathway of anaerobic degradation of organic waste.

Pretreatment enhances the digestibility of organic substrate, and it is broadly classified into five major groups. They are physical, chemical, biological, mechanical and combinative pretreatments. **Figure 2** shows pretreatment methods and their classification. Physical pretreatment is further classified into two: thermal [2] microwave [3] and freezing and thaw [4] pretreatments. Chemical pretreatment is further classified into two: alkaline [5] and acidic [6] pretreatments. Biological pretreatment is further classified into two: enzyme [7] and fungal [8] pretreatments. Mechanical pretreatment is further classified into two: high-pressure homogenizer [9] and ultrasonic [10] pretreatments. Combinative pretreatment such as thermo-chemo-sonic [11], thermo-chemo-disperser [12], thermo-chemo-ozone [13] and hydrothermal [14] pretreatment, etc. Many researchers have experimentally proven the positive effect of pretreatment on hydrolysis and subsequent biogas production [15].

Acidogenesis is the second step involved in AD process; in this step, acidogenic microbes are responsible for conversion of hydrolyzed organics into ethanol (C_2H_5OH), acetate (CH_3COO^-), hydrogen (H_2), carbon dioxide (CO_2) and other acids (propionic, formic, lactic, butyric, succinic acids). In some cases, amino acids cause formation of ammonia. Eqs. (2)–(4) show that the reaction occurs during acidogenesis phase as shown below:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2 \tag{2}$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \tag{3}$$

$$C_6H_{12}O_6 \rightarrow 3CH_3CH_2OH \tag{4}$$

Acetogenesis is the third step involved in AD process. In this step, acetogenic microbes are responsible for conversion of long-chain fatty acid, volatile fatty acid and alcohols into acetic acid (CH_3COOH), hydrogen (H_2) and carbon dioxide

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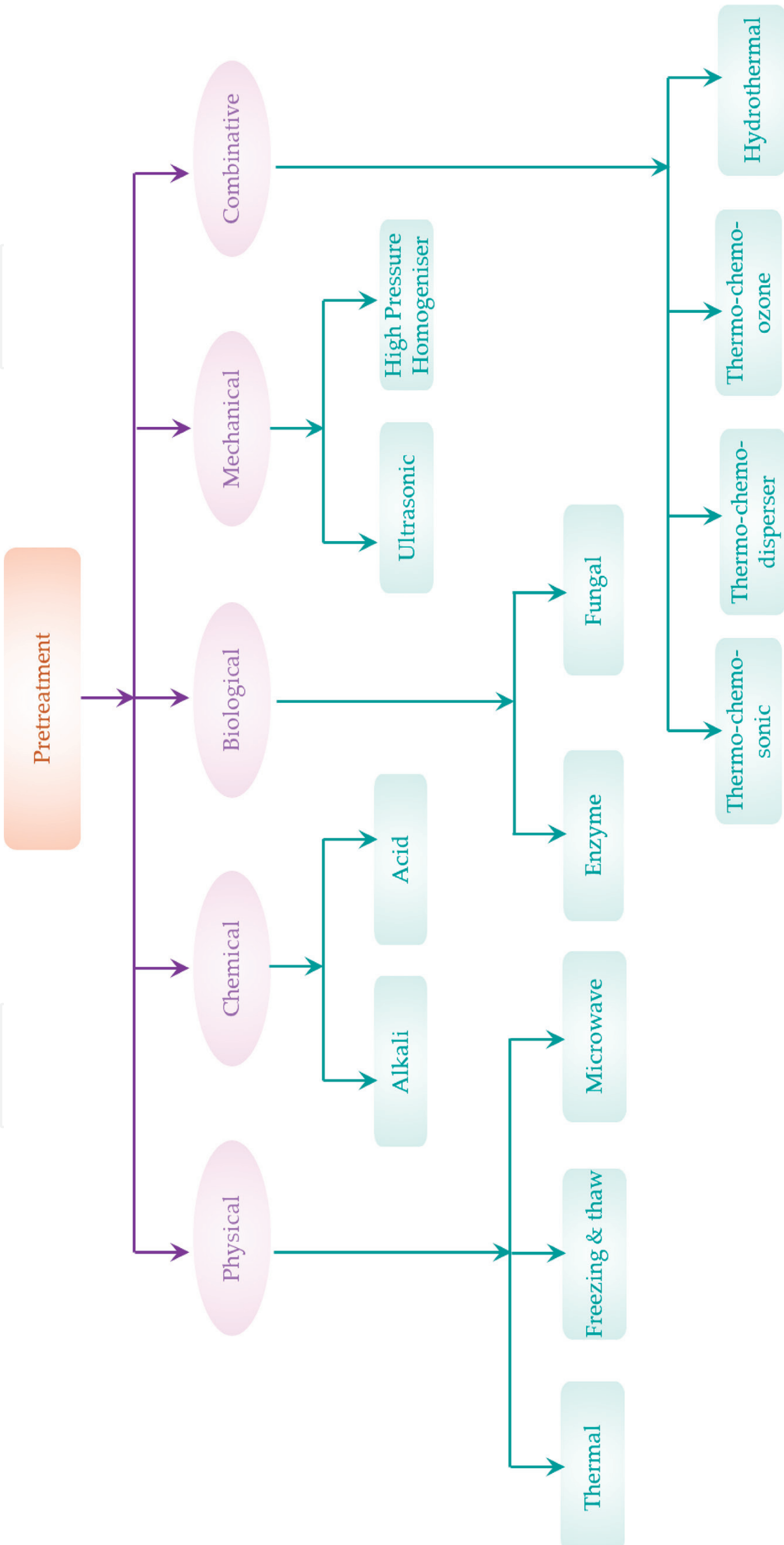

Figure 2.
Pretreatment methods and their classification.

(CO_2). Eqs. (5)–(7) show that the reaction occurs during acetogenesis phase as shown below:

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2 \quad (5)$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2 \quad (6)$$

$$CH_3CH_2OH + 2H_2O \rightarrow CH_3COO^- + 3H_2 + H^+ \quad (7)$$

During this conversion process, the concentration of biological and chemical oxygen demand in the medium gets reduced. On the other hand, the hydrogen partial pressure is generated due to the presence of hydrogen gas inside the reactor. Methanogenic microbes, present in the digester, consume accumulated hydrogen gas.

Methanogenesis is the final step of anaerobic degradation of organic waste. In this step, methanogenic microbes are responsible for converting the acetic acid and hydrogen into methane (CH_4) gas and carbon dioxide (CO_2). Eqs. (8)–(10) show that the reaction occurs during methanogenesis phase as shown below:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (8)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (9)$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (10)$$

Methane-enriched biogas can be a promising source to displace the use of conventional fossil fuel. Biogas acts as a flexible energy source, which can be used for various applications like power, heat, transport and feedstock for chemical production. Biogas is the most significant product of (AD) process, and it comprises 60–70% of methane (CH_4) gas, 25–35% of carbon dioxide (CO_2) and remaining 5–10% of other corrosive gases. Biogas was more suitable to replace the demand of conventional fuel. Biogas has a calorific value of 6.0–6.5 kWh/m^3, which varies according to the percentage of biomethane content in the biogas. In addition to this, AD process indirectly reduces the cost of energy and fuel production. On the other hand, anaerobically digested residues have market value due to its nutrient content. It can be used as bio-fertilizer for agriculture crop production. AD process is termed as a golden process to eliminate the emission of GHG and reduce global warming issues.

According to the World Bioenergy Association 2017 report, the global biomethane production was approximately 35 billion m^3 of methane. Overall, global biogas production was 1.28 EJ in the year 2014. Developed countries like the United States and Europe are the major contributors of biogas production throughout the world. Among them Europe is the world's largest biomethane producer. Around 18 billion m^3 of biomethane was produced in the year 2015; it was half of the global biogas production. The produced biomethane was utilized for generation heat, electricity and transportation (vehicle fuel). Nearly 50% of total biogas was utilized for heat generation, and around 697 biomethane filling stations were employed in Europe [16]. Developing countries in Asia (India, China, Bangladesh, Pakistan, Sri Lanka and Nepal) and Africa (Burkina Faso, Ethiopia, Tanzania, Kenya and Uganda) are very successful in the operation of domestic scale digester. In Asia, approximately 47.876 million of domestic scale digesters were effectively operated to meet their daily needs. In that, China holds first place and accounts for 43 million domestic scale digester, India 4.75 million, Nepal 330,000, Bangladesh 36,000, Sri Lanka 6000 and Pakistan 4000. Similarly, Africa holds 60,000 domestic scale digesters, in that Kenya leads first place and accounts for 16,419, Ethiopia 13,584, Tanzania 13,037, Uganda 6504 and Burkina Faso 7518. Produced biogas was utilized for cooking and lighting purposes.

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