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State of the art and future concept of food waste fermentation to bioenergy

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ABSTRACT

Food waste (FW) has been a major concern worldwide due to its large amount of production and improper disposal methods. Nevertheless, FW has been considered as a promising feedstock for the production of bioenergy employing the dark fermentation and anaerobic digestion technologies. The production of bioenergy from FW would not only solve the disposal problems of FW but will also help in the reduction of greenhouse gases while replacing the usage of coal, fuel and natural gas. This paper reviews the biotechnological aspects of the FW to bioenergy conversion processes. The first section covers the present available technologies and various process parameters involved in FW to bioenergy production. Next section describes various works reported on combined handling of FW co-digested along with various other substrates for bioenergy generation. Third section reviews the available microbiomes in FW that can be harnessed for bioenergy production. Subsequent section proposes a framework for FW biorefinery to broaden the scope of FW use in bioenergy sector and presents the case studies of pilot-scale operations of FW to bioenergy.

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1. Introduction

The global population is increasing exponentially leading to increasing dependency on fossil fuel and imparting huge pressure on the energy crisis impeding sustainable development. This ever-increasing dependency on fossil fuels has contributed to climate change and global warming, thus leading to severe impact on the environment. In this current century there is a paradigm shift on reuse of waste and the research on conversion of waste to green energy. There is a renewed interest in the search for new, cleaner and green energy source. In the scope for search of new cleaner and sustainable energy, research efforts have mainly focused on energy carriers such as hydrogen, ethanol, butanol, biodiesel, and methane. More recently research has been also focused on biohythane and hythane, which are a mixture of hydrogen and methane [1,2]. Hythane®, a mixture of natural gas and hydrogen, usually has 5–7% hydrogen which makes it a high value gas fuel for vehicles and combustion engines [3]. Biohythane production technology is considered more energy-efficient because it involves anaerobic digestion which is a simpler process for conversion of acetate to methane after the acidogenic phase of hydrogen fermentation [4].

Energy carriers produced from food crops have caused inflation in food prices and led to food crisis [5]. Hence, the production of bioenergy from various wastes such as plant waste, including agricultural residues and domestic organic wastes including FWs is now paramount in positive shift towards green energy production. FW has greater sustainability than any other biomass waste in producing biofuels, in particular, biomethane and biohydrogen. A recent review on FW also suggests that it has great potential for energy production [6]. Food and Agricultural Organization of the UN has published a report which mentions that nearly 1/3rd of the global food produced for human consumption is becoming a waste and it is estimated to be 1.3 billion tons per year [7]. According to US Environmental Protection Agency, FW is defined as "uneaten food and food preparation wastes from residences and commercial establishments such as grocery stores, restaurants, and produce stands, institutional cafeterias and kitchens, and industrial sources like employee lunchrooms". More than 40% of FW in the industrialized countries is at the retail and consumer level, while in developing countries, this occurs in the post-harvest and processing level [7]. Bioenergy generation from such large amount of global FW would therefore be the most appropriate method for its management.

Bioenergy in the form of biohythane will not only support electrical energy but will also reduce the problems associated with landfills like greenhouse gas emissions. Biohydrogen from FW can either be used directly as energy in transportation sector or, electricity harnessed from hydrogen based fuel cells, since it can be considered as environmental friendly green energy as it generates water as its by-product for energy generation of 142 $kJ\ g^{-1}$, which is almost three times more than other available hydrocarbon fuels [8]. On the other hand, combustion of methane which is generated mostly by anaerobic digestion process involving a complex series of reactions mediated by certain specific groups of microorganisms [9] evolves carbon dioxide and hence not considered a green alternative fuel. Nevertheless it is estimated that sufficient electricity can be generated which can power over 2.5 million homes for a year if half of the FW generated each year in the USA is subjected to anaerobic digestion [10]. It is also argued that small-scale anaerobic digestion systems are more suitable in the urban buildings to save on transportation costs and reducing the amount of FW sent to landfills [11] in addition to FW management practices [12–14].

In recent years there has been a renewed interest in research focusing on production of biohythane from FW [15–17]. Since biohythane is a mixture of hydrogen (10–25% by volume) and methane, it is a perfect fuel owing to its clean nature than methane, high fuel efficiency, improved heat efficiency, and making engines easy to ignite with less input energy [18]. This review paper is an overview of the microbial science and engineering aspects of the FW to bioenergy technology focusing on methane, hydrogen and biohythane production, and is organized as follows: Section 2 has an overview of operational conditions affecting FW fermentation, Section 3 is on co-digestion of FW with other auxiliary substrates, Section 4 presents the microorganisms in FW fermentation, and Section 5 proposes the future concepts and reviews the feasibility of pilot-scale operations. In this review article, the term "bioenergy" refers to single-phase hydrogen and/or methane, and two-phase hydrogen-methane gases, and has been dealt collectively in each section.

2. Process operation and current technological status

The process of hydrogen fermentation and anaerobic digestion of waste is well established. Hydrogen is generated as a product of acidogenesis and acetogenesis in anaerobic digestion process, which rapidly gets consumed by methanogenic population in the single-phase digestion. However, pre-treatment of seed inoculum by heat treatment can eliminate the methanogenic population resulting in production of only hydrogen and carbon dioxide in the biogas [19,20]. On the other hand, the two-phase fermentation system can recover both hydrogen and methane by separation of acidogenesis and acetogenesis; and methanogenesis [21–23]. The single-phase anaerobic process is generally more predominant than two-phase for the full scale application [24]. However, two-phase anaerobic digestion is shown to achieve higher overall degradation efficiency and is more advantageous than the single phase system for the treatment of FW and its conversion to bioenergy [22]. Below sub-sections have been framed to deal with both single-phase and two-phase hydrogen and methane production in an effort to focus on bioenergy from FW irrespective of the type of energy gases (hydrogen or methane) that are produced.

2.1. Types of reactors

The feasibility of using an array of batch and continuous reactors for anaerobic fermentative processes leading to hydrogen and methane production has been investigated over the years and is therefore not discussed in great detail in this review. A few such reactor types have been discussed here which were operated on FW as the feedstock (Table 1).

2.1.1. Continuous stirred tank reactor

Continuous stirred tank reactors (CSTRs) have been employed by several researchers for biohydrogen production from FW (Table 1). Specifically, the usage of intermittent-continuous stirred