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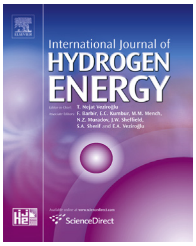

Effects of microwave and ultrasound irradiations on dark fermentative bio-hydrogen production from food and yard wastes

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Lignocellulosic materials like food and yard wastes are difficult to hydrolyse and this results in decreased bio-hydrogen yields. As such, this study investigated the potential of microwave (MW) and ultrasound (UtS) irradiations for pre-treating food and yard wastes prior to dark fermentation. The specific energy was varied from 0 to 6946 kJ/kg total solids for each pre-treatment and the results obtained showed that both pre-treatments generally enhanced solids and organic matter solubilisation, with the effects more significant at high pre-treatment conditions. However, none of the pre-treatment conditions improved bio-hydrogen production. The main reasons identified for the low H_2 yields were the possible formation of inhibitors due to pre-treatments while the higher concentrations of propionic acid and ethanol among the end-product metabolites could also have suppressed bio-hydrogen production. Consequently, neither MW nor UtS irradiation is feasible as pre-treatment of food and yard wastes for enhanced bio-hydrogen production under the range of specific energies studied.

Introduction

Bio-hydrogen production from the dark fermentation process has acquired growing interests over the years owing to the clean and non-polluting nature of H_2 upon combustion as well as its high energy content [1,2]. Nonetheless, the technology is not currently commercialised due to the low bio-hydrogen yield obtained, making the technology economically unsustainable [3]. Several factors have been reviewed to affect dark fermentative bio-hydrogen production and one of these is the inaccessibility of cellulose molecules from lignocellulosic materials for attack by microorganisms [4,5]. In lignocelluloses such as food and yard wastes, the cellulose molecules are protected from hydrolysis by a lignin seal and this eventually results in incomplete hydrolysis followed by reduced bio-hydrogen production [4–8].

To solve this problem, several studies have investigated the potential of pre-treating the substrates prior to dark fermentation to assist in cell wall disruption and delignification of biomass so as to release cellulose molecules into solution [4,5,9]. Furthermore, pre-treatment also helps reduce cellulose crystallinity so that hydrolysis into simple sugars is enhanced [4,9] and this is followed by an increased accessibility of these sugars to microorganisms for conversion into bio-hydrogen [10]. Among the different techniques that have been investigated for substrates pre-treatment prior to the dark fermentation process, microwave (MW) and ultrasound

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(UtS) irradiations are gaining increasing interests due their potential to enhance bio-hydrogen production [11,12].

The principles underlying MW irradiation as pre-treatment include athermal (non-thermal) and thermal effects [13,14]. Non-thermal effects are created by constantly changing dipoles which result in the breakdown of hydrogen bond [15,16], potentially enhancing solubilisation. As for thermal effects, these are related to increases in temperature and subsequently pressure which causes destruction of cell walls and the transfer of organics from the particulate to the soluble phase [5,13,16–18]. The increased concentration and availability of soluble organics for degradation by microorganisms subsequently results in an increase in bio-hydrogen production as reported by Thungklin et al. [11]. While many studies have investigated the use of MW irradiation as substrate pre-treatment prior to the dark fermentation process, most of these have used the technology in combination with a chemical pre-treatment technique such as acid or alkali while also focussing on only crop residues as substrates [17,19–25]. Consequently, investigations on standalone MW irradiation as pre-treatment are scanty in literature while the few studies that have investigated standalone MW irradiation as pre-treatment prior to dark fermentation have been limited to only sludge or microalgae as substrates [11,26]. As such, there is currently no study, to the author's knowledge, on the use of standalone MW irradiation as pre-treatment of food and yard wastes prior to dark fermentation.

As for UtS irradiation, the factors behind substrates pre-treatment include thermal effects caused by cavitational collapse, shearing forces and the formation of free radicals that assist in cell wall rupture and increased solubilisation [27,28]. Further to enhanced solubilisation, increase in bio-hydrogen production has been reported in literature [12]. However, similar to MW irradiation, most of the studies on sonication have focussed on substrates viz. crop residues [29,30], wastewater [31–34], sludge [35–37] or algal biomass [26,38–41]. Nonetheless, there are some studies that have focussed on sonication of food wastes prior to dark fermentative bio-hydrogen production, with some of them reporting enhanced H_2 yields following pre-treatment [12,42–44] while Wongthanate et al. [45] reported decreased H_2 yield following ultrasound irradiation. Similar to MW irradiation, there is currently no study, to the author's knowledge, on the use of UtS irradiation as pre-treatment of a mixture of food and yard wastes prior to dark fermentation.

Besides the lack of studies on MW and UtS irradiations as pre-treatment of food and yard wastes, the absence of studies on standalone MW-irradiation is also surprising. Furthermore, only a few studies has compared the effects of MW with UtS irradiation as substrates pre-treatment [46,47]. As such, a comparative analysis of the effects of MW and UtS irradiations for a wide variety of substrates such as food or yard wastes and other lignocellulosic materials remains to be investigated. In the same line, there exists currently no study that has compared the effects of MW and UtS irradiation on dark fermentative bio-hydrogen production. As such, the aim of this study was to investigate and compare the effects of standalone MW and UtS irradiation of food and yard wastes on solids and organic matter solubilisation and subsequently, on dark fermentative bio-hydrogen production. The results of this study will thus help fill in some of the aforementioned research gaps in the field of MW and UtS pre-treatments.

Materials and methods

Inoculum and pre-treatment

Digestate was collected from an anaerobic digester treating primarily cow manure and food wastes and was used as the seed microflora. The total solids (TS) and volatile solids (VS) concentrations of the untreated microflora were 4.23 ± 0.06% and 74.56 ± 0.26% respectively while the pH was 7.69 ± 0.08. Before the fermentation process, the inoculum was irradiated in a MW oven (Trust TMW-17MX03W, 700 W, 2450 MHz) at full power intensity to obtain a MW specific energy (SE) of 5000 kJ/kg TS so as to repress hydrogen consuming-bacteria and promote hydrogen-producing bacteria. The pre-treated inoculum was then allowed to cool to room temperature and the TS content was adjusted to 4.3% prior to dark fermentation to obtain a constant basis for all set-ups.

Substrates and pre-treatment

The substrates used in this study consisted of 50% food wastes and 50% yard wastes (wet weight basis). The food wastes, comprising of bread (28%), tea wastes (25%), potato peels (23%), rice (14%) and banana peels (10%) (wet weight basis), were blended using a kitchen blender (Moulinex) and stored at 4 °C prior to use. The TS and VS contents of the blended food wastes were 32.38 ± 1.35% and 97.27 ± 0.62% respectively. Yard wastes consisted of dry branches, green leaves and grass (based on a VS ratio of 1:2:1) (modified from Ref. [48]) with an initial TS content of 36.4% and VS content of 94.47 ± 0.23%. The yard wastes were dried at 60 °C for 24 h in an oven (Blue M Electric Company), ground in a grinder-pulveriser (Fritsch) to pass through a 2-mm screen and stored in air-tight plastic bags prior to use.

Microwave irradiation

Food and yard wastes were mixed in a ratio (1:1) (wet weight basis) and water was added to reach a desired TS content of 6%. The prepared mix (henceforth referred as the substrates) was then placed in a polypropylene container covered with a plastic lid to minimise evaporation of water and VS. The plastic lid was equipped with a small hole to prevent pressure build-up in the container during pre-treatment. The use of ambient pressure is preferred as it promotes cell wall rupture due to intracellular water evaporation [16]. The substrate was irradiated in the same MW oven (as for inoculum pre-treatment) (Trust TMW-17MX03W, 700 W, 2450 MHz) at varying power intensities and pre-treatment times from 0 to 30 min to obtain different SE of 0–6946 kJ/kg TS as depicted in Table 1. SE was calculated as per Eq. (1) [49,50].

$$SE = (P \times t)/(V \times TS_o) \quad (1)$$

where SE is the specific energy (kJ/kg TS); P is the power (W); t is the pre-treatment time (s); V is the volume of substrates