Potential use and the energy conversion efficiency analysis of fermentation effluents from photo and dark fermentative bio-hydrogen production

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Effluent of bio-hydrogen production system also can be adopted to produce methane for further fermentation, cogeneration of hydrogen and methane will significantly improve the energy conversion efficiency. Platanus Orientalis leaves were taken as the raw material for photo- and dark-fermentation bio-hydrogen production. The resulting concentrations of acetic, butyric, and propionic acids and ethanol in the photo- and dark-fermentation effluents were 2966 mg/L and 624 mg/L, 422 mg/L and 1624 mg/L, 1365 mg/L and 558 mg/L, and 866 mg/L and 1352 mg/L, respectively. Subsequently, we calculated the energy conversion efficiency according to the organic contents of the effluents and their energy output when used as raw material for methane production. The overall energy conversion efficiencies increased by 15.17% and 22.28%, respectively, when using the effluents of photo and dark fermentation. This two-step bio-hydrogen and methane production system can significantly improve the energy conversion efficiency of anaerobic biological treatment plants.

1. Introduction

Given its high energy density and lack of pollution emission when combusted, hydrogen has been recognized as the ideal alternative energy to fossil fuels (Zhang et al., 2017a; Kumar et al., 2015). Biological hydrogen production, with its mild processing conditions, abundant raw material sources, and low energy consumption, has attracted the attention of various researchers (Singh and Wahid, 2015; Urbaniec and Bakker, 2015). Biological hydrogen production mainly includes photo and dark fermentation (Chandrasekhar et al., 2015). Photosynthetic bacteria (PSB) utilize several small-molecule volatile acids and monosaccharides in the fermented liquid, such as acetic acid, pyruvic acid, and butyric acid, as organic substrate to produce hydrogen (Pere and Nimalalakhandan, 2010; Mizuno et al., 2000). Whereas, dark-fermentation bacteria decompose macromolecular organic matter into organic acids and alcohols (Barca et al., 2015; Li et al., 2010). The decomposition process provides energy and reducing power for the growth of dark-fermentation bacteria, removal of cumulative electrons, and quick release of hydrogen.

Broadly speaking, the bio-hydrogen production process is an intermediate stage of methane production by anaerobic digestion; hence, the utilization rate of substrates is low. Owing of this, a certain amount of volatile fatty acids remains in the effluent at the end of the fermentative process, which results in low energy conversion efficiency. Direct discharge of fermentative effluents causes environmental pollution (Cheng et al., 2010; Xie et al., 2008). Ozmihic and Argun investigated bio-hydrogen production by the photo fermentation of dark-fermentation effluent from ground wheat starch. The content of volatile fatty acids in the dark-fermentation effluent decreased significantly during the photo-fermentative reaction (Ozmihic and Kargi, 2010; Argun et al., 2008). Therefore, dark-fermentation effluent can be effectively utilized as the substrate for photo fermentation bio-hydrogen production (Silva et al., 2015; Dahiya et al., 2015). The effluent can also be utilized as a carbon source for the culture of microbes (Chi et al., 2011). Combined dark- and photo-fermentation bio-hydrogen production has been demonstrated by several studies (Tawfik et al., 2014; Rai et al., 2014). Ghimire et al. (2016) used dark-fermentation effluent as the substrate to produce hydrogen from photo-fermentation, and then poly-β-hydroxybutyrate (PHB), resulting in 80% COD removal.

In recent times, single-stage processes that are a hybrid of dark and photo fermentation are gaining attention. First, dark-fermentation bacteria consume complex organic substrates, and then the volatile fatty acids byproducts are utilized by PSB. Temperature, pH, and effluent rate all have significant influence on hydrogen production; the total hydrogen output under optimum conditions increase by up to four times (Zagrodnik and Laniecki, 2015; Ngoma et al., 2011). Yeshanew et al. (2016) integrated the systems of continuously stirred tank reactor (CSTR) and anaerobic fixed bed reactor (AFBR) to evaluate the bio-hythane (bio-H₂+CH₄) yield from food waste; HRT and effluent

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recirculation rate were investigated, and optimal parameters were obtained. Short HRT was found good for bio-hydrogen yield, and recirculation of the AFBR effluent provided alkalinity to the whole system, which maintained the pH in a suitable range for the growth and metabolism of the hydrogen producing bacteria. Several factors such as a nature of substrate, microbial consortium, and reactor configuration influence the process of bio-hydrogen and subsequent bio-methane production from waste biomass by dark fermentation technology (Liu et al., 2013). Methanogenic archaea grow slowly and are a vulnerable microbial group. Given that methanogenic archaea can utilize volatile fatty acids as substrates, the methane production process can be the final stage in the anaerobic fermentation process (Aydın et al., 2015). Some scholars have conducted the bio-hydrogen and bio-methane production process from cow dung, waste water, starch-rich biomass, and etc. (Intanoo et al., 2014; Reungsang et al., 2012; Zhu et al., 2008). However, little research has been done using fallen leaves (Song et al., 2013). Methanogenic archaea grow slowly and are a vulnerable microbial group. Given that methanogenic archaea can utilize volatile fatty acids as substrates, the methane production process can be the final stage in the anaerobic fermentation process (Aydın et al., 2015). Some scholars have conducted the bio-hydrogen and bio-methane production process from cow dung, waste water, starch-rich biomass, and etc. (Intanoo et al., 2014; Reungsang et al., 2012; Zhu et al., 2008). However, little research has been done using fallen leaves (Song et al., 2013). Methanogenic archaea grow slowly and are a vulnerable microbial group. 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