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Feasibility of bio-hythane production by co-digesting skim latex serum (SLS) with palm oil mill effluent (POME) through two-phase anaerobic process

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ABSTRACT

Hydrogenogenic batch fermentation without nutrients addition was investigated at different SLS: POME mixing ratios of 100:0, 95:5, 90:10, 85:15, 80:20, 75:25, 70:30, 65:35, 60:40, 55:45,50:50, and 0:100 (Volatile Solid, VS basis) at initial organic concentrations of 21 and 7 g-VS/L. Satisfactory hydrogen yield of 84.5 ± 0.7 mL H_2/g-VS_{added} was achieved from 7 g-VS/L batch having SLS: POME-VS mixing ratio of 55:45. Adding $NaHCO_3$ 3 g/L or 0.43 g-$NaHCO_3$/g-VS) in the two-stage anaerobic system at 7 g-VS/L could provide sufficient buffering capacity. Hydrogenogenic effluent from 7 g-VS/L batch at SLS: POME mixing ratio of 55:45 (VS basis) could further generate rather high methane yield of 311.2 ± 8.0 mL- CH_4/g-VS_{added} in themethanogenic stage.According to the experimental results, bio-hythane approximately 55.5 × 10^6 m^3/year with 21% (V/V) of hydrogen, equivalent to51.0 × 10^6 L-gasoline could be produced potentially from 3.88 × 10^6 m^3 of mixed SLS and POME through the two-stage anaerobic co-digestion.

Introduction

Humankind are majorly concerning about greenhouse gases emission generated mainly by fossil fuels combustion, depleting petroleum reserves and argument of the coupling food-biofuels produced from agricultural crops. Sustainable and environmentally friendly bio-fuels produced from non-food biomass and organic wastes have been therefore motivated to investigate for securing the future supply of food and

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energy carriers and to preventing the future environmental pollution and climate change. Such non-food biomass i.e. agricultural residues, organic wastes, animal manure, and algae can be potentially converted into various bio-energy carriers (bioethanol, biohydrogen, biogas, and biobutanol, etc.,) by applying micro-biological processes [1].

Conventional dark fermentation, which is the original first acidogenic stage in the anaerobic digestion process, could be currently applied for hydrogen producing from carbohydrates rich substrates. However, hydrogen production yield is kinetically limited at less than a theoretical yield of 498 mL-hydrogen/g-sugars, accounting to only less than 33.3%of the energy content (carbon source) in carbohydrates. Thus, the single dark fermentation is not economically feasible since more than 66.7% of the rest energy contained in carbohydrates is still in the liquid form, contained mainly with volatile fatty acids (VFAs). The sequential stage of anaerobic acetogenesis-methanoges is could enable easily to convert VFAs generated to methane for recovering energy and stabilizing soluble organic matters. Currently, a coupling process of dark fermentation and anaerobic digestion, practically well known as a two-stage process is appeared as an attractively novel, promising, and technically and economically feasible technology for producing a mixture of hydrogen and methane, so-called bio-hythane from various carbohydrate substrates. Bio-hythane is qualified byaround 10–15% by volume of hydrogen generated from the first stage of dark fermentation. Hythane is already known as high value added gaseous bio-fuel, which is more powerful and less releasing greenhouse gases than single biogas [2]. Recently, two-stage anaerobic process has been reported that it could recover energy yield from food waste [3], liquid fraction of lignocellulosic biomass [4], and vinasse [5] by 20%, 33%, and 10.8%, respectively higher than one-stage process.

Skim latex serum (SLS), acidic yellowish wastewater containing high amounts of organic matters, ammonia nitrogen, and sulfate is majorly generated from concentrated latex factories mostly located in Southern Thailand annually around 1.85×10^6 m^3. Since hydrogen sulfide (H_2S), generated from sulfate containing in SLS by sulfate reducing bacteria could cause inhibition to anaerobic microorganisms at even low H_2S levels of 0.002–0.003 M as stated by Batstone et al., 2002 [6]. Thus, the two-stage anaerobic digestion of SLS for simultaneous bio-fuel production and organic waste stabilization was suggested. Bio-hydrogen yield of 41.3 mL-H_2/g-VS and bio-methane yield of 321.0 mL-CH_4/g- VS were achieved satisfactorily from SLS-anaerobic digestion at 22.8 g-VS/L concentration by deploying batch two-stage process under thermophilic conditions [7]. However, that cultivation was still with addition of essential nutrients in the form of basic anaerobic (BA) medium for ensuring optimal growth conditions. For industrial application, the two-stage anaerobic digestion process is not cost effective for supplementation with those essential nutrients [8]. Alternatively, co-digesting SLS as nitrogen rich substrate with others carbon rich substrates could be cost-effective to produce bio-hythane. Generally, anaerobic co-digestion between different substrates aimed to supply missing nutrients and buffers, establish synergistic effect of microorganisms, dilute potential toxic compounds for effective and economical production of gaseous bio-fuel at high load of biodegradable organic matter has been previously suggested by Angelidaki and Ellegaard, (2003) [9].

Palm oil mills, another major agro-industries in Southern Thailand, generates large amount of around 6×10^6 m^3/year of wastewater so-called palm oil mill effluent (5–7.5 m^3-POME for producing one ton of crude palm oil). POME is defined as carbohydrates rich substrate containing large quantities of nutrients. Consecutive hydrogen and methane potentials were successfully achieved from batch two-stage anaerobic digestion of POME without nutrients addition [10]. Thus, co-digesting SLS having nitrogen rich substrate with palm oil mill effluent (POME), carbon rich substrate could potentially be the simplest and most suitable approach to enhance hydrogen and methane production, economically. Since having high temperature (80–90 °C), POME could be better microbial processed under thermophilic conditions to eliminating the need of cooling system. Furthermore, anaerobic thermophiles constituted in mixed cultures have been previously investigated for their good potential to producing bio-hydrogen and methane from individual digestion of both SLS [7] and POME [10]. Anaerobic co-digestion of different mixed substrates i. e. food waste and brown water [11], waste activated sludge and organic fraction of municipal solid waste [12] and palm oil decanter cake and crude glycerol [13] has been demonstrated for effective bio-hythane production and organic waste stabilization.

Bio-hythane is qualified by around 10–15% by volume of hydrogen generated from the first stage of dark fermentation [2]. Thus, optimization for mixing ratio of individual substrates to achieve satisfactory hydrogen production from co-digestion is essentially required. In this investigation, the main objective is therefore to evaluate feasible hydrogen production in a term of biochemical hydrogen potential (BHP) of mixed SLS and POME at designed VS based mixing ratios and followed by evaluating methane production from the selected hydrogenogenic effluents in a term of biochemical methane production (BMP) as a simulated two-stage anaerobic process proposed by Giordano et al. (2011) [14]. BHP [15] or BMP [16] is primarily deployed to evaluate potential substrates by determining ultimate hydrogen or methane production from certain amount of organic matters containing in substrates. Additionally, Batch BMP assays and presumably also batch BHP assays could be also used to determine the first-order kinetic constant [16], which is further utilized for preliminary design of the continuous anaerobic digester's size and organic loading rate [17]. Since, bicarbonate buffering reagent is playing a vital role on microbial growth. Different concentrations of $NaHCO_3$ solution was additionally investigated for possible enhancing hydrogen production in batch fermentation having judgmentally proper SLS: POME mixing ratio.

Materials and methods

Inoculum preparation

Fermentation broth originally achieved from 1.35-L lab-scale continuously stirred tank reactor (CSTR) for bio-hydrogen production from mixed substrate of POME and SLS was used