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Anaerobic digestion of skim latex serum (SLS) for hydrogen and methane production using a two-stage process in a series of up-flow anaerobic sludge blanket (UASB) reactor

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ABSTRACT

A series of up-flow anaerobic sludge blanket (UASB) reactors operated under thermophilic conditions was used to investigate the two-stage anaerobic process for continuous hydrogen and methane production from skim latex serum (SLS). The first reactor for producing hydrogen was operated by feeding 38 g-VS/L-SLS at various hydraulic retention times (HRTs) of 60, 48, 36, and 24 h. The optimum hydrogen production yield of 2.25 ± 0.09 L-H_2/L-SLS was achieved at a 36 h HRT. Meanwhile, the effluents containing mainly with acetate was fed to the second UASB reactor for methane production at 9-day HRT and could be converted to methane with the production yield of 6.41 ± 0.52 L-CH_4/L-SLS. The efficiency of organic matters removal obtained from this two-stage process was 62%. The present study shows high value fuel gases in a form of hydrogen and methane can be potentially generated by using a continuous two-stage anaerobic process, in which available organic matters is simultaneously degraded.

Introduction

Concentrated latex with 60% dry rubber content (DRC) is majorly produced with annual production capacity of around 1.3×10^6 metric tons from concentrated rubber latex plants, which are mostly located in Southern Thailand in 2013 [1]. Skim latex serum (SLS) is major wastewater generated during a stage of sulfuric acid coagulation of skim latex to recovering remained rubber. In concentrated latex processing, approx.

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405 Tons of concentrated latex produced could discharge 580 m^3 of SLS [2]. Thus, around 1.85×10^6 m^3/year of SLS is currently generated. Without proper treatment and management, SLS could cause seriously environmental pollution due to containing high amounts of organics, ammonia (for natural latex preservation), and sulfuric acid. Currently, SLS is prior mixed with wastewaters from other unit operations in concentrated latex processing and then is treated widely by combination of aerated lagoon/activated sludge system and anaerobic/facultative pond, which are open systems [3,4]. However, aerobic treatment process has high operating cost and generates large amount of waste activated sludge, which needs to be further anaerobically stabilized [5]. While open anaerobic system could emit methane and hydrogen sulfide, respectively by degradation of organic matters and sulfate. Methane is one of major greenhouse gases, while hydrogen sulfide has extremely unpleasant odour of rotten eggs.

Close treatment system of conventional anaerobic digestion is then attractive to overcome mentioned limitations. Anaerobic digestion of high organic matters contained in SLS could be possibly promising to producing sustainable energy carrier in a form of biogas and treating organic wastes, simultaneously. However, substrate containing high sulfate could cause methanogens inhibition, resulting in anaerobic process instability and consequently obtaining low biogas production yield [3,4,6]. Alternatively, the two-stage anaerobic digestion process, in which hydrolysis/acidogenesis and acetogenesis/methanogenesis takes place in separated reactors, could convert carbohydrate rich substrates into hydrogen in the acidogenic stage and sequential convert organic acids generated from the first stage into methane in the second methanogenic stage [7]. A mixture of hydrogen and methane in a ratio containing 10–60% (V/V) of hydrogen called hythane, which is considered as more powerful and less releasing greenhouse gases i.e. CO, CO_2 and NO_x than single biogas/natural gas [8].

Meanwhile, sulfate reducing bacteria also contained in the stage of acidogenesis could simultaneously convert sulfate into hydrogen sulfide gas, which is easily released from the fermentation broth. Consequently, main toxicity of sulfide to methanogens in the second stage is reduced [3,6]. In addition, since containing significant amount of nutrients for microorganisms growth in a form of non-rubber matters, including proteins, carbohydrates, sugars, and organic and inorganic salts, SLS could therefore possibly be converted to hydrogen and methane by anaerobic microorganisms by applying this mentioned two-stage process. In previous batch experiments of thermophilic two-stage anaerobic digestion process, satisfactory results of bio-hydrogen and bio-methane yields of 1.57 ± 0.06 L-H_2/L-SLS and 12.20 ± 0.31 L-CH_4/L-SLS were achieved, respectively by using initial SLS concentration of 22.8 g-VS/L [9]. Under thermophilic conditions, thermophiles having more thermodynamic favorability than mesophiles could increase chemical and biological reaction rates [10]. Although a continuous two-stage anaerobic digestion has been investigated to evaluate the performance on treating latex processing wastewater [3,6], no investigation on using sole SLS as substrate for hydrogen and methane production in this continuous two-stage process.

In order to develop the two-stage anaerobic digestion process being practical and economical for stable hydrogen and methane production in a commercial scale, the continuous process is necessary to be applied [11]. An up-flow anaerobic sludge blanket (UASB) reactor is defined as a small high rate reactor, which could retain anaerobic microorganisms in a form of biological granules, leading to have solid retention time (SRT) being much higher than hydraulic retention time (HRT). Organic wastewater with low suspension solid (SS) content can be effectively degraded at high dilution rates by using UASB reactor [12]. Furthermore, the UASB reactor is generally able to tolerate high toxic compound in the incoming wastewater [13].

The aim of this research project was to investigate the feasibility of utilizing SLS as harsh substrate to generate hydrogen and methane production, continuously by using thermophic two-stage anaerobic digestion process in a series of two (UASB) reactors. The valuable information obtained from this research work would be useful for further development of a series of pilot scale reactors for producing gaseous biofuel in a form of mixed hydrogen and methane by applying a two-stage anaerobic digestion of SLS based.

Material and methods

Skim latex

SLS was kindly supplied by Chana Latex Co, Ltd., Songkla (Southern Thailand) and stored at 4 °C until further use. Its characterizations were previously analyzed [9] and are presented in Table 1.

Experimental set-up and operation

In this investigation, 2 UASB reactors with 1350 mL and 2800 mL working volume were carried out in series for H_2 UASB reactor (R1) and CH_4 UASB reactor (R2), respectively. Both UASB reactors were maintained at 55 °C by circulating hot water inside a water jacket surrounding UASB reactors.

Methanogenic granular sludge was obtained from industrial biogas plant using wastewater generated from fishery frozen factory in Songkla, southern Thailand. The granules were autoclaved at 121 °C for 30 min to remove methanogenic activity [7]. 400 mL granules were added into the R1 reactor as

Table 1 – Characteristics of skim latex serum (SLS).

Parameter	Concentration
Chemical oxygen demand: COD (g/L)	35.83 ± 1.7
Sulfate (mg/L)	3580 ± 130
pH	4.97 ± 0.21
Total alkalinity (mg/L-$CaCO_3$)	553 ± 18
Total nitrogen (TKN) (g/L-N)	5.18 ± 0.18
Total organic nitrogen (g/L)	1.21 ± 0.08
Carbohydrates (g/L)	5.1 ± 0.18
[a]Protein (g/L)	7.56 ± 0.5
Total solid (g/L)	41.3 ± 0.70
Volatile solid (g/L)	38.0 ± 0.83

[a] Protein (g/L) = 6.25*[total organic nitrogen].