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Feasibility evaluation of fermentative biomass-derived gas production from condensed molasses in a continuous two-stage system for commercialization

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ABSTRACT

The excessive burning of fossil fuels is one of the main sources of emissions of carbon dioxide (CO_2) which causes the greenhouse effect. The effect could be resulted in climate changes and disorder of our ecosystem. Thus, bioenergy developments will play important roles to help decreasing CO_2 emission for better global environment in the future. In the domain of biohydrogen production, biomass including: cellulose, wastewater and agricultural waste are the main resources to maintain feedstock demand. Developing sustainable energy with sustainable feedstock sources like sugary wastewater by using two-stage biomass-derived gas production system might bring great economic profits to business. In this study, the system will be chosen to testify its sustainability when producing the sugary wastewater to renewable source energy. The commercial potential analysis is derived from the internal rate of return (IRR). The novelty finding of this study, as the result showed, found out that the energy recovery is 1.12 times higher than single stage. According to the IRR analysis with the calculated years of 15 years, the IRR is 32.47% that means the system can payback within 3.19 years. Therefore, the feasibility of commercialization potential of biomass-derived gas production system can be verified.
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Introduction

With rapidly developing industries, fossil fuel is greatly employed as fuel for energy source, which results in greenhouse effect and environmental destruction. Therefore, developing sustainable energy is important to our ecological environment. When it comes to fermentative biohydrogen production, it acquires with many advantages such as organic degradation with low cost, high heat and clean energy output,

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operation without light and low pollution. Several researchers focused on two-stage of biohydrogen and biomethane production technology for enhancing energy recovery efficiency. According to previously research studies, some of researchers used one-stage and two-stage system to compare the potential of commercial feasibility. The result has shown that the two-stage system has advantage to enhance bioenergy production [1–3]. During the first stage, organic matters such as glucose, starch and sucrose were used for biohydrogen production. During the second stage, the community for biomethane production consumes the fatty volatility acid to generate biomethane. In addition, two-stage system is able to yield hythane fuel for combustion, which can effectively reduce carbon dioxide and carbon monoxide [4–7]. The single stage processes has traditionally been used for biohydrogen production and for biomethane production are focused on energy generation. In biomethane production bioreactor, bacteria were converted substrate into energy. The technology of two-stages combined biohydrogen and biomethane production is outstanding because the effluent from biohydrogen reactor can be used as substrate for microorganism metabolizing to generate biomethane and effectively increasing organics degradation [8,9]. The differences between traditional anaerobic digestion of single stage and two-stage system during fermented process include hydrolysis, acidogenesis, methanogenesis that can increase treatment efficiency, efficiency of degradation, total reaction rate, total biogas production, and easier to control the operated conditions under mesophilic and thermophilic environment [10–13]. For commercial scale-up, two-stage fermented system was employed as economic system for feasibility evaluation.

Therefore, two-stage biomass-derived energy production system has potential to be commercialized. The economic evaluation of bioenergy production system is vital to dark fermentation because cost decides benefits and revenue. There are numerous ways to be applied for bioenergy application, such as biomass-derived energy, electricity, and heat. However, biomass-derived gas can be sold directly without pretreatment, which is the convenient way to increase the income. Commercial potential establishment is necessary for obtaining reliable data to scale-up biomass-derived energy production system.

In 2012, Li et al. has reported that biohydrogen was generated from pretreated textile wastewater with dark fermentation in batch system. The textile wastewater was obtained from the de-sizing process in a textile factory. As the result showed, the best biohydrogen yield is 1.37 mol H_2/mol reducing sugar [14]. In 2011, Chu et al. has published a biohydrogen production system from immobilized cells and suspended sludge with condensed molasses which was used directly without pretreatment. In this study, the simulation data was obtained from Chu et al. research, hydrogen production rate increased by increasing feedstock concentration from 40 to 60 g COD/L within the HRT 2–4 h [15]. According to the previous research study, it reveals that biohydrogen has great potential to become a main renewable energy source for future bioenergy development.

The Aspen Simulation has possession of excellent property databanks and a useful tool to examine performance by combining process simulation with economic calculation [16,17]. In the recent studies, there are multitudinous researchers who use Aspen Plus to carry out economic evaluation on diverse industries. In 2013, Nasr et al. have published a research about carbon dioxide capture evaluation with Aspen Plus, which was compared with other research studies on high energy penalty being taken from the power plant and requires signify capital investment [16]. Abbas et al. employed Aspen Plus software to focus on oxygen and water removal simulation from the carbon dioxide product stream. The result detailed process modeling and techno-economic evaluation are performed and the potential of capture technology was proved [17]. In addition, Aspen Plus was employed to evaluate the economic feasibility for improvement of biogas production by Shafiei et al. [18]. Aspen Plus is the best method chosen to simulate the biohydrogen production process with dark fermentation and the parameters. It was used as reference for commercial model building.

When it comes to bioenergy commercialization, in industrial company, the economic evaluation aimed at feasibility of two-stage biogas production system is vital to practical applications. In the recent studies, researchers have used Aspen Plus and IRR for economic evaluation and verifying market value. The research studies including biohydrogen production via bio-oil gasification and bio-oil reforming [19], monosaccharide production via fast pyrolysis of lignocellulose [20], two-stage process for fermentative hydrogen production [21], bio-refining of lignocellulosic feedstock [22], and autotrophic microalgae for fuel production [23] are evaluated by Aspen Plus simulation and IRR.

Therefore, in this study, Aspen Plus simulation and IRR were employed as tool to simulate and calculate the market value of this process.

Process development

In terms of economic evaluations, researchers use Aspen Plus to do process simulation and economic evaluation, which is vital to biomass-derived energy future development that reveals feasibility to carry out eco-friendly environment [16–18]. According to this study, Aspen Plus was employed to evaluate the process of continuous pilot scale of biomass-derived gas (biohydrogen and biomethane) production system. IRR was employed in capital budgeting to measure and compare the profitability of investments.

Pilot and feedstock

Due to bioenergy pilot, which located at Feng Chia University (Taichung, Taiwan), the working volume was chosen as the same size. The working volumes of biohydrogen and biomethane, with mixing systems, were 0.38 and 2.4 m^3, respectively. The system was composed of pipes, mixing tanks, heating system, and pumps for maintaining biomass-derived energy production. The parameters setting followed the real scale, and kinetics calculation carried out with lab-scale data for evaluating the potential of Feng Chia bioenergy production system. Apart from that, in this case, condense molasses was chosen as feedstock which was sugary wastewater from food industrial companies. The cost of high condense molasses was

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