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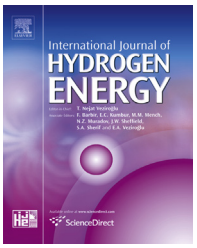

Techno-economic analysis of a novel bioprocess combining solid state fermentation and dark fermentation for H_2 production from food waste

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ABSTRACT

The techno-economic analysis of a novel bioprocess combining solid state fermentation and dark fermentation for H_2 production from food waste (FW) was investigated. A H_2 production plant was designed with capacity of 10 ton/day and lifetime of 10 years. Aspen Plus was utilized to simulate the mass and energy balance of the plant. It was noticed that the total capital investment, annual operation cost and annual revenue of the plant were USD707850, USD366700/year and USD574800/year, respectively. The payback period of the plant was 5 years with internal rate of return of 20.2%. The H_2 market price and operating labour cost were the most important parameters on the net present value of the plant. The unit H_2 production cost was USD2.29/m^3 which was cheaper than the H_2 market price (USD2.7/m^3). The results demonstrated that the combined bioprocess was economically feasible for industrial H_2 production.

Introduction

The depletion of fossil fuel and the severe environmental pollution caused by the usage of fossil fuel have forced the researchers to look for the alternative energy sources [1]. H_2 is regarded as a promising energy carrier since it is renewable and clean [2,3]. Furthermore, it could be used in fuel cells for electricity production [4]. At present, chemical or thermochemical ways are commonly used for H_2 production from fossil fuel, while a cost-effective method is still in great demand [5]. Biological H_2 production, which could use raw materials as substrate to produce H_2, has attracted considerable attention [6,7]. Generally, biological H_2 production could be separated into dark fermentation and photo fermentation. Compared to the photo fermentation, dark fermentation seems to be more attractive since it could produce H_2 with the absence of light. However, the high production cost is a major obstacle to realize dark fermentative H_2 production for industrial application [8]. Using organic wastes as feedstock for dark fermentative H_2 production is considered to be an attractive solution [9,10].

Food waste (FW), which is produced 1.3 billion ton/year in the world [11,12], is regarded as an important part of municipal solid waste (MSW). The traditional methods for MSW disposal, such as landfill and incineration, are not proper to treat FW due to the limited land space and emission of toxic

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gas [13,14]. FW could be used as substrate for biofuels production (such as dark fermentative H_2 production) since it contains a great amount of starch and protein [15,16]. However, these nutrients need to be hydrolysed into glucose and free amino nitrogen (FAN) prior to be utilized by microorganisms which is considered to be the limiting step for dark fermentative H_2 production [17,18]. It is reported that the physical and chemical pretreatments of FW are able to accelerate the hydrolysis speed, while the inhibitory products for dark fermentative H_2 production are also generated [19]. Enzymatic hydrolysis of FW seems to be an attractive method since the nutrients (glucose and FAN) could be released from FW with high hydrolysis speed and low cost [20,21].

In light of the above analysis, a novel bioprocess combining solid state fermentation (SSF) and dark fermentation for H_2 production from FW has been successfully developed [22,23]. It has been proved that the hydrolysis rate and H_2 yield could be effectively increased by this novel bioprocess. Therefore, the aim of the present work is to perform the techno-economic analysis of the combined bioprocess. This study could provide a protocol to build a bioenergy plant from organic wastes in practical application.

Materials and method

Description and advantages of the combined bioprocess for dark fermentative H_2 production from FW

The flow of the combined bioprocess for H_2 production from FW was shown in Fig. 1. The bioprocess included five phases: pretreatment and SSF, enzymatic hydrolysis of FW, seed culture, dark fermentative H_2 production and biogas purification.

In the pretreatment and SSF phase, FW was ground and used by fungi (*Aspergillus awamori* and *Aspergillus oryzae*) via SSF to produce the solid enzymes (glucoamylase and protease), respectively. The produced solid enzymes were then used to hydrolyse the pretreated FW to obtain the FW hydrolysate which was rich in glucose and FAN. In the seed culture phase, the H_2-producing bacteria of *Biohydrogenbacterium* R3 were cultured. The FW hydrolysate was pumped into the fermentor, where the R3 converted the FW hydrolysate to H_2 and CO_2. Finally, the produced biogas was purified by the purification system.

As a design basis, a feed of 10 ton/day of FW was selected. In addition, the heat exchanger was arranged to reduce the energy loss [24]. Aspen Plus was used to simulate the mass and energy balance of the H_2 production plant [25,26].

The low hydrolysis rate and nutrient conversion efficiency are the main obstacles to realize dark fermentative H_2 production from FW for industrial application [16,18]. In the previous study, a novel bioprocess combining SSF and dark fermentation for H_2 production from FW has been successfully developed with the maximum H_2 yield of 52.4 ml H_2/g FW [23]. This result was comparable or higher than other literatures [15,18] since the liquid FW hydrolysate rather than solid FW was utilized as feedstock and the ratio of starch conversion could achieve 96.2% within 24 h. Other reported pretreatments could convert a small part of the starch, while the bigger parts of starch retained in the solid FW [17]. So, the combined bioprocess could be a promising method for industrial H_2 production due to the lower hydrolysis speed and higher nutrients conversion rate and H_2 yield.

Detailed bioprocess description

Table 1 showed the composition of the FW used in this study. FW was collected and transported to the H_2 production plant and stored in the tanks (E1). Then, FW was ground into smaller size in E2. Solid-state fermentation was performed in two reactors (E3) from pretreated FW by *A. awamori* and *A. oryzae*, respectively. The reactors (E3) were incubated to obtain the solid enzymes (glucoamylase and protease) at 30 °C for 4 days.

After the pretreatment and SSF, enzymatic hydrolysis of FW was performed in a bioreactor (E4) with the produced enzymes at temperature of 55 °C and agitation speed of 500 rpm. Water was introduced into the bioreactor (E4) with pretreated FW to provide a liquid medium for mixing. In order to reduce the energy loss, the heat exchanger (E5) was used to improve the efficiency of the H_2 production plant. The mixture was then centrifuged (E6) to produce the FW hydrolysate which was further utilized as the substrate for dark fermentative H_2 production.

Biohydrogenbacterium R3, the accession number of NCBI nucleotide sequence database was AY363375 [27], was used as the H_2-producing bacteria. It was cultivated in a shake flask (E10) at 37 °C, followed by seed fermentation (E9) with FW hydrolysate. The culture was purged with N_2 to ensure the anaerobic condition [28].

Dark fermentative H_2 production from FW hydrolysate was performed in a fermentor (E7) at 37 °C. *Biohydrogenbacterium* R3 was inoculated into the fermentor (E7) with inoculum size of 2% by volume. Dark fermentative H_2 production was purged with N_2 and agitated at 300 rpm. The pH was automatically kept within 4.0–4.6 using sodium bicarbonate and sulphuric acid. The effluent of the H_2 production fermentor was centrifuged (E8) to get the soluble microbial product (SMP) which could be further utilized for biological methane production.

Finally, the produced biogas was introduced and purified in the purification system (E11). It was reported that 8% of the produced H_2 could be lost and the purity of H_2 could reach 99% [25].

Economic analysis of the H_2 production plant from FW

Estimation of total capital investment

The total capital investment (TCI) for a new plant consisted of the fixed capital cost (FCC), land cost and working capital cost (WCC). The FCC included the equipment purchase cost and the additional cost for the set-up of the plant. As a waste recycling and renewable energy production program, the local government would support to built the plant and provide the land for free. The WCC of the plant could be regarded as 6.5% of the FCC [21]. So, the calculation of TCI could be expressed as the following Eq. (1).

$$TCI = FCC + WCC \quad (1)$$

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