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英文论文题目: Study on Enhancing Biohythane Production from Tofu (Soybean) Processing Residue via Pretreatment and Anaerobic Digestion

申请人姓名: MAHMOUD MOHAMED AHMED HUSSEIN ALI

指导教师: 盛奎川 教授

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ABSTRACT

Biofuel generation from biomass has received more attention as an alternative, renewable, sustainable, and clean energy source that replaces fossil fuel, alleviating energy demand and environmental concerns. Among biomass, tofu processing residue (TPR), which is a by-product of the tofu and soymilk production industry, is rich in carbohydrates (50-60%), proteins (20-30%), and fats (10-20%), as well as contain high moisture content ($\geq 85\%$), posing it as a suitable substrate for biofuels production through anaerobic digestion (AD) technology. TPR deteriorates rapidly and is thus mainly disposed of in landfills, causing environmental concerns. Therefore, how to efficiently treat TPR is a big concern for soybean processing plants. AD is the most sustainable and cost-effective method to treat organic wastes along with energy recovery as well as it reduces the emission of greenhouse gases, generated during the self-decomposition of biowastes. In this research, energy recovery from TPR was improved by the production of biohythane from one-stage and two-stage AD through controlling the operational conditions, pretreating TPR using ultrasonic pretreatment, dilute sulfuric acid (H_2SO_4) pretreatment, and the simultaneous combination of ultrasonic and dilute H_2SO_4 pretreatments, as well as adding molybdate (MoO_4^{2-}) and ferric chloride (FeCl_3). The main results are as follows:

1) Two-stage AD of TPR was investigated considering the impacts of operational conditions on microbial community diversity and biohythane production. The results showed that the optimal conditions were dark fermentation (DF) operated at the substrate to inoculum ratio (SIR) of 8 and 37°C for 36 h, followed by methanogenic fermentation (MF) performed at the SIR of 1 and 37°C for 13 d, which produced 324.4 ml/g- VS_{fed} of biohythane along with 103 mmol/L acetic acid and 38 mmol/L propionic acid. Two-stage AD improved specific energy recovery by 41.5% compared to one-stage AD, producing a biogas yield of 189.6 ml/g- VS_{fed} . SIR and temperature affected microbial community diversity of DF system, where high SIR of 8 speciated hydrogen producers such as *Mobilitalea* and *Clostridium sensu stricto 1* at thermophilic and mesophilic temperatures, respectively, whereas low SIR of 0.5 stimulated methane generation by the speciation of *Methanoculleus thermophilus*. Likewise, hydrogenotrophic methanogens (*Methanomassiliicoccus*) enriched MF reactors operated at low SIR. Overall, this study demonstrated two-stage AD as an efficient technology for producing clean energy and value-added products using TPR.

2) TPR has received more attention as a source of bioenergy. However, their low solubility has hindered biohythane generation. Consequently, the ultrasonic and H_2SO_4 pretreatments were combined and compared for the first time to improve the hydrolysis of organic matter and carbohydrates as well as to increase free amino nitrogen generation from TPR. Besides, the impact of pretreatments on biohythane generation via one-stage AD was also investigated. Under the optimal conditions of 7.54% substrate level, 8% H_2SO_4 concentration, 80 °C, and 50 min, the coincident ultrasonic- H_2SO_4 pretreatment enriched the contents of soluble chemical oxygen demand, reducing sugar, and free amino nitrogen to 49675 mg/L, 26 g/L, and 1721 mg/L, respectively, greater than individual pretreatments. Also, Biohythane yield increased by 4.20-12.58% over control (389.39 ± 23.8 ml/g- VS_{fed}). Furthermore, the highest hydrogen yields of 42.5 ± 2.08 and 28.1 ± 1.07 ml/g- VS_{fed} and the sulfate removal efficiencies of 93 and 92% were achieved with ultrasonic- H_2SO_4 and H_2SO_4 pretreatments, respectively, indicating the enhancement of acidogenic and sulfidogenic activity.

3) Biohythane production through one-stage AD of sulfate-rich hydrolyzed TPR has been hampered by high H_2S production. Herein, two-stage AD was investigated with the addition of MoO_4^{2-} (0.24-3.63 g/L) and FeCl_3 (0.025-5.4 g/L) to the DF stage to improve biohythane production. DF supplemented with 1.21 g/L MoO_4^{2-} increased hydrogen yield by 14.6% compared to the control (68.39 ml/g- VS_{fed}), while FeCl_3 had no effective effect. Furthermore, the maximum methane yields of MF were 524.75 ml/g- VS_{fed} with 3.63 g/L MoO_4^{2-} and 521.60 ml/g- VS_{fed} with 0.6 g/L FeCl_3 compared to 466.07 ml/g- VS_{fed} of the control. The maximum yields of biohythane and energy were 796.7 ml/g- VS_{fed} and 21.80 MJ/kg- VS_{fed} with 0.6 g/L FeCl_3 when the sulfate removal efficiency was 66.71%, and H_2S content was limited at 0.08%. Therefore, adding 0.6 g/L FeCl_3 is the most beneficial in improving energy recovery and sulfate removal with low H_2S content.

Keywords: Sulfuric acid pretreatment, Ultrasonic pretreatment, Anaerobic digestion, Biohythane, Ferric chloride, Molybdate

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LIST OF ABBREVIATIONS

AD: Anaerobic digestion	SO ₄ ²⁻ : Sulfate
ACE: Abundance coverage-based estimator	SO ₃ ²⁻ : Sulfite
CH ₄ : Methane	S ₂ O ₃ ²⁻ : Thiosulfate
CO ₂ : Carbon dioxide	SEM: Scanning electron microscopy
C/N: Carbon to nitrogen	TPR: Tofu processing residue
COD: Chemical oxygen demand	TS: total solid
CH ₂ O: Formaldehyde	VFAs: Volatile fatty acids
Chao1: Species richness estimator	VS: Volatile solid
COA: Coenzyme A	5-HMF: 5-hydroxymethylfurfural
DF: Dark fermentation	
FAN: Free amino nitrogen	
FeCl ₃ : Ferric chloride	
GHGs: Greenhouse gases	
H ₂ : Hydrogen	
H ₂ S: Hydrogen sulfide	
H ₂ SO ₄ : Sulfuric acid	
HCl: Hydrochloric acid	
H ₃ PO ₄ : Phosphoric acid	
KOH: Potassium hydroxide	
MF: Methanogenic fermentation	
MoO ₄ ²⁻ : Molybdate	
NH ₄ -N: Ammonium nitrogen	
NaOH: Sodium hydroxide	
NMDS: Non-metric multidimensional scaling analysis	
POME: Palm oil mill effluent	
SIR: Substrate to inoculum ratio	
SRB: Sulfate-reducing bacteria	
SLR: Solid loading ratios	
SCOD: Soluble chemical oxygen demand	