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BIOHYTHANE (METHANE AND HYDROGEN) REGENERATION FROM AGRICULTURAL BIOMASS RESIDUE: POSSIBLE OR UTOPIA?

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Abstract: This mini review is mainly on the initial discussion to the point-of-view of the conceptual bioenergy factors of anaerobic digestion towards biohythane (hydrogen and methane) production. Currently, the recent attention from the highly organic wastewater discharge as a major contribution to biohythane production rate. Then, few reviews on the strategies which had been applied to improve the biohythane production from the existing anaerobic digestion are revealed from the collective literature. A lot of efforts have been made to emphasize on the co-digestion and biomass retention improvement within the digester, but has a limited discussion on the utilization of solid biomass (especially agricultural residue) as the main substrate. Other studied strategies to the realization of biohythane from agro-biomass include the selective pre-treatment, additives supplementation (co-digestion and co-mixing of the substrate), bioreactor modifications and engineering influential factors for the controlled process. By integrating the suitable pre-treatment facility and operating the two-stage of anaerobic digestion technology, these applied strategies had become a positive and successive response to the biohythane production.

Keywords: Agricultural biomass, volatile fatty acids, renewable energy, biohythane, sustainability.

Introduction

Agricultural biomass is the major commodity for countries economic growth, especially in the ASEAN region due to the most significant income for developing countries or low-to-middle income society. Commonly, the agriculture activity includes seedlings, fertilizing, cultivating and harvesting of crops with the emphasizes on the quantity and quality of the products. The leftover fraction of the processed crop (biomass residual) is referred to as agro-industrial crop residue (or wasted biomass material). Generally, these residues are either bagasse, the spent fibrous pulp left behind from stalks of crops, or seed coats, shells, and husks. Recently, agricultural residue (typically biomass and its component) has been massively explored in the concept of waste-to-wealth or under the framework of the Circular Economy agenda (Jones *et al*., 2020). The usage of this component of biomass as an energy resource could be the best option for cost-saving and practical solutions in waste management. However, the crucial review on bioenergy generated from highly organic wastewater is the most highlighted study since a few decades ago (Krishnan *et al*., 2019). Relatively, some of the discussion majorly on the combination of few strategies in treatment technologies [Macintosh *et al*., 2019], substrate and co-mixing carbon sources (Krishnan et al., 2017), microbial consortium (Zhang *et al*., 2019) and optimization of various engineering factors (Mishra *et al*., 2017) towards the better energy yield.

Agricultural biomass residue may consist of various types of carbohydrate, protein, micro, and macro-nutrients but the most widely content in solid forms are hemicellulose/cellulose and lignocellulose compounds that are difficult to be treated in the conventional treatment system. Moreover, the components may also serve as a raw material in the production of alternative liquid (bio-ethanol and biodiesel) and gaseous fuels (bio-methane and pyrolysis gas) from the specific treatment processes. But, most of the reports summarize as the feasible raw material for the burning process and biofuel (such as bioethanol) (Rezania *et al*., 2019). Furthermore, biomass and biomass-based fuels can readily be transported to the areas with no access to naturally available renewable energy, as the main criteria in translating waste-to-energy framework for community relevancy. The most agricultural countries (e.g. Malaysia, Indonesia, Philippines, etc.) could tap into this significant implementation as an alternative source of renewable energy resources. However, the great challenges are awaiting, including investment costs, policy, technology and sustainability of the system. The total potential recoverable bioenergy from the main agricultural and agro-industrial residues generated have been published elsewhere (Go *et al*., 2019). Based on the low-cost and practical solution for bioenergy generation from biomass, a biohythane concept was proposed in this writing. The concept is similar to the ordinary treatment from liquid form (wastewater), nevertheless, the pre-treatment (the breakdown of cellulose into fatty acids) could be a promising solution in the process. Hythane is an emerging alternative fuel that contains a mixture of hydrogen and methane that can be transported and stored using current natural gas infrastructure [Hora *et al*., 2018]. Blending small percentage of H2 (10–25%) in methane, the hythane gas is shown to significantly extending the combustion rate and increasing the lean limit of combustion, proving it to be a promising fuel to improve the efficiency of methane-fueled vehicles if succeeds. Biohythane can be realized through a two-stage separate microbial or fermentation that is connected in series, separating acidogenesis and methanogenesis [Krishnan *et al*., 2016]. Hydrolysis and acidogenesis occur during the first stage. The bacteria are grown under an optimal pH range of 5–6 for 1 to 3 days, which they can convert carbohydrates, proteins and lipids to sugar, amino acid and fatty acid, after that the production of hydrogen, acetate and butyrate along with other by-products of propionate, ethanol, and lactate. In the second stage, the remaining organic content in the acidogenesis effluent is anaerobically converted to methane under a neutral pH range of 7–8 for 10 to 15 days by methanogens.

As focussed on the biohythane concept, the outline of the biochemical regeneration and thermodynamics challenges of its production by comparing with other biological processes for energy production from waste agricultural-biomass are reviewed in many kinds of literatures [Moustakas, *et al*., 2019]. The technical challenges are highlighted towards scale-up of biohythane production process, which is the most crucial since 10 years ago including the optimization criteria of biohydrogen reactor, the energy efficiency of biohythane system, and system engineering. In most of the prominent substrate that could convert into bio-hydrogen and bio-methane is the volatile fatty acids. As the residual of agricultural having possible high content of sugar, starch, carbohydrates, and hemicellulose, the medium/short fatty acid will be potentially generated from the fermentation processes. Volatile fatty acids (VFAs), as the main components of the fermentation residuals in anaerobic fermentation, can be further converted into energy carriers such as methane [Gracia *et al*., 2019], hydrogen [Magnin *et al*., 2019], or other biochemicals [Dey *et al*., 2019] by establishing a two anaerobic stage which is known as dark fermentation.

Methane fermentation from the anaerobic process has been well developed in several publications [lay *et al.*, 2019; Kazimierowicz *et al*., 2019; Vu *et al*., 2019], which is, however, the most challengeable issue in treating high-solid organic waste [Cheng *et al*., 2020] as well as material recovery merit. Instead, the biohythane system via various anaerobic processes has resulted in enhanced energy recovery and reduced fermentation time. In addition, in a biohythane system dealing with typical lignocellulosic biomass, saccharification and biohydrogen production could be simultaneously implemented in the first stage via natural cultivation of targeted microbial consortium engineering. This is concluding that it remains a great challenge for long-term stable operations treating low-grade (residual biomass) complex feedstock, such as lignocellulosic biowaste [Catal *et al*., 2019]. Using microbial consortium (that usually under specific environmental modification) enriched from nature may be more competitive for biohythane production from real biowastes [Seengenyoung *et al*., 2019].

Challenges in Engineering in Recent Publications

The use of biomass as an energy source is often criticized for its impacts on the biodiversity, land use, and the food supply [Huth *et al*., 2019]. However, these impacts are dependent on the type of biomass used. Biomass may further be classified according to its source as forest biomass, agricultural biomass, microbial biomass, or livestock wastes. Agricultural biomass is often reported as the conflicting agenda with food crops, which at the same time are themselves, energy crops (HHV=15–25 MJ/kg [Peyrot *et al*., 2019], leading to the competition of their use as either food or fuel. A great strategy to address the competition and appropriation of the targeted agricultural biomass is through the strategy in larger quantities vegetation or the cultivation of non-edible energy crops, instead of the using residual biomass generated at the downstream processes. This, however, would not lead to the competition of land use and consequently, least affecting the ecological biodiversity. Considering the harvesting and processing of crops, residues (almost 40–60% of biomass processed) will be produced, which can become resources for energy production without having to compete with food supply and land use [Wicaksono *et al*., 2019]. Therefore, non-edible and agricultural biomass residue would be the main criteria in translating the potential biohythane in the field.

Anaerobic digestion, as a common procedure in the enhancement of bioenergy producer, is a microbial-dependent biological process, that is highly dependent on survivability and metabolism activity [Siddique *et al*., 2019]. The breakdown of cellulose into fatty acid components shall be the proposed pre-treatment at the pilot-scale setup. A pre-treatment via biological, chemical and thermal process will be directly affected by the properties of the biomass (substrate or feedstock). This is because the feedstock, which plays a significant role as the food to be digested by the microorganisms (after the pre-treatment), comprises the major living conditions within the anaerobic digestion system. However, in the cultivation of microbial biomass, it requires substrates for growth and metabolic activities which are oftentimes derived from agricultural biomass. In addition, many of these microbial cultivation technologies are still in its infancy and may not be widely available or accessible. Therefore, a strategy of pre-treatment via the biological system is more preferable as compared to others [Zaied *et al*., 2019].

Concluding Remarks

Agricultural, non-edible biomass and the most intense of agro-industrial crop residues are among the versatile substrate for bioenergy production due to its composition and macronutrient availability. Utilizing these agricultural resources would allow the displacement of a significant fraction of the fossil fuels, without necessarily resulting in a competition in the supply for food and fuel (food-energy nexus). The idea of utilizing agricultural biomass residue and wastes from agro-industry materials is the practical solution in facilitating low-cost technology via two-stage fermentation. All types of agricultural biomass residue from sugarcane, paddy rice, palm oil, coconut, and corn are the top produced crops in many low-middle income countries. The increase in the production of these crops would result in the subsequent increase in the generation of agricultural and agro-industrial crop residues, further improve the alignment in addressing the needs as an alternative for the energy sector. Biohythane as the new alternative energy derivation from organic residual biomass would be a great challenge in the existing engineering and technology platform. However, the conceptual of pre-treatment from biological metabolism is further to be investigated in the near future.

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