Methane Production from Biomass Wastes by Anaerobic Fermentation (Vol. 5) : Feasibility Study of Biological Hydrogen Methanation Process

Summary

A study was made on the issues of biological hydrogen methanation, which is the production of methane, using methane, carbon dioxide, and hydrogen that are generated in the methane fermentation process of waste biomass, and also hydrogen generated from electrolysis of water and other processes for making up the deficient of hydrogen. The cost of producing methane using this process is 6.9 JPY/MJ, which is slightly more expensive than the current gas rate of 3.5 JPY/MJ plus the DAC cost, which is 5.7 JPY/MJ, but given the benefit of treating waste biomass, biological hydrogen methanation is worthwhile. Studies on fermenter components and system optimization will be needed.

Proposals for Policy Development

- Biological hydrogen methanation has not yet been fully developed in Japan. It is necessary to promote the elucidation of the fermentation mechanism of fermenting bacteria, the development of reaction engineering that accelerates the dissolution of hydrogen, and the effective utilization of waste biomass.
- For methane fermentation, analysis using the fermentation model used in this study will be beneficial for studying the rationalization of the process, leading to the prediction of the fermentation system. It is important to study the fermentation model and spread this process to be widely used.

1. Methane fermentation model

The fermentation pathways via ethanol [2] and lactic acid [3], which are important in hydrogen fermentation, were added to the ADM1 model [1] that has been used as a base. As a result of streamlining the process and predicting the fermentation system, the amount of methane and hydrogen produced were able to be determined when conditions such as initial NH_4 concentration and temperature were changed. These results can be used to study the conditions for methane and hydrogen production by biomass fermentation.

2. Investigation of biological hydrogen methanation ([4], [5])

The cost and amount of methane produced by the fermentation-methanization process using CO_2, H_2, and CH_4 produced by methane fermentation of biomass wastes were investigated. The reaction equation is as follows:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O\ (g),\ \Delta\ Hr\ (\text{heat of reaction}) = -165\ kJ/mol\text{-}CH_4$$

Two types of systems were studied: (Case 1) a two-stage system consisting of a hydrogen fermentation tank and a methane fermentation tank, and (Case 2) a system in which the hydrogen fermentation tank was removed for simplification and both raw garbage and sewage sludge were fed into the methane fermentation tank.

3. Studied model and cost of methane gas

A model of methane gas production by methane fermentation from waste biomass (sewage sludge and food waste) and biological hydrogen methanation was studied for a city with a population of 100,000.

The process flow for Case 1 is shown in Fig. 1.

The amount of methane produced is calculated to be 97 m^3/h (95% methane), which can replace 9% of the gas energy consumed by a city of the same size. Methane gas is easier to use for consumer purposes than hydrogen, including safety aspects.

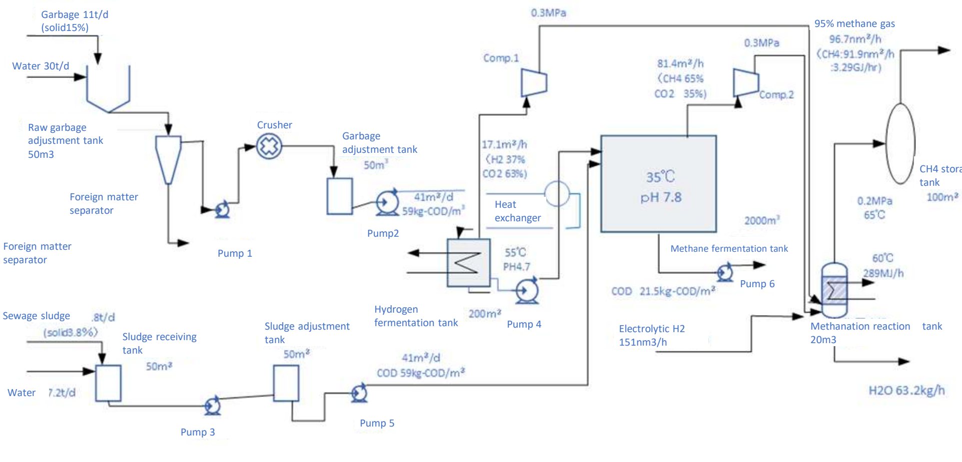

Fig. 1. Flow chart of the bio-methanization process

The methane production cost was calculated from fixed costs such as the construction and operating costs of the model, and variable costs such as electricity and supplied hydrogen (Table 1). However, if fossil fuel-derived methane is used, the CO_2 generated must be captured by DAC in a zero-carbon society. This will cost 2.2 JPY/MJ, which together with the current gas price of 3.5 JPY/MJ, will result in a cost of 5.7 JPY/MJ. The costs of methane production for the entire process is 7.0 JPY/MJ for Case 1 (with hydrogen fermentation) and 6.9 JPY/MJ for Case 2 (without hydrogen fermentation), which is a little more expensive than that of fossil fuel-derived methane. Considering the benefit of treating the waste, this reaction system is worthwhile.

Table 1. Methane production cost
Methane production rate: 91 Nm^3/h, 3.26GJ/h(26.1 TJ/y)

CH_4 production cost

	Case 1		Case 2		Remarks
Fixed cost		Fixed cost burden		Fixed cost burden	
Construction cost	453million JPY	68million JPY	396million JPY	59million JPYy	Annual expense ratio 15%
Operating costs	9 people	45million JPY/y	9 people	45million JPY/y	5 million JPY/ person/ year
Total		**4.3JPY/MJ**		**4.0JPY/MJ**	
Variable cost	**Specific "energy" or "material" consumption**	**Cost (JPY/MJ)**	**Specific "energy" or "material" consumption**	**Cost (JPY/MJ)**	**Unit price, etc.**
Electric power	40.5 kWh/GJ	0.481	34.7 k Wh/GJ	0.416	12JPY/ k Wh
Sewage Sludge	0.305 t /GJ	0	Same as left	0	
Garbage	0.100 t /GJ	0	Same as left	0	
Hydrogen	46.3Nm3/GJ	2.29	50.0Nm3/GJ	2.5	50JPY/Nm 3
Generated heat(60℃)	88.6MJ/GJ	Δ0.104	Same as left	Δ0.104	1.17JPY/MJ(=1.5JPY/MJ× 333/423)
nutrient	Ammonium phosphate 0.129kg/GJ KCl 0.073 g /GJ	0.021	Same as left	0.021	Produced water: 19.2kg/GJ Ammonium phosphate: 140JPY/kg, KCl: 45JPY/kg
Total variable cost		**2.7JPY/MJ**		**2.9JPY/MJ**	
CH4 Production cost		**7.0JPY/MJ**		**6.9JPY/MJ**	

[1] D.J. Batstone, et.al, 'Anaerobic Digestion Model No. 1', Scientific and Technical Report No. 13, IWA publishing, 2002.
[2] E.Shi, J.Li, and M.Zhang, Water Res., 161 (2019) 242-250.
[3] G.Antonopoulou, et. al, Int. J. Hydrogen Energy, 37 (2012) 191-208.
[4] B. Lecker et al. Bioresource Tech., 245 (2017) 1220-1228.
[5] D. Rusmanis et al, Bioengineered, 10 (2019) 604-634.

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