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Potential Renewable Energy from Tofu Processing Waste in Banda Aceh City, Indonesia

M. FAISAL[1,*], I. MACHDAR[1], F. MULANA[1] and H. DAIMON[2]

[1]Department of Chemical Engineering, Syiah Kuala University, Jl. Syech A. Rauf, Darussalam, Banda Aceh, Aceh 23111, Indonesia
[2]Department of Environmental and Life Science, Toyohashi University of Technology, Tempaku Cho, Toyohashi, Aichi 441-8580, Japan

*Corresponding author: Fax: +62 651 52222; Tel: +62 651 7412301; E-mail: mfaisal@unsyiah.ac.id

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The potential renewable energy from tofu processing industries in Banda Aceh city of Indonesia and their waste characteristics have been studied. There are 10 tofu processing industries in Banda Aceh with raw materials capacity ranging from 150-500 kg/day for each industry. Totally, about 45,900 kg of wastewater produced from 2,550 kg/day soybean in Banda Aceh. Currently, the waste has been disposed into the environment and river without any treatment, causing bad odours and pollution of the surface and ground water. The management of this waste with high water content represents an economic problem because of the high costs for disposal, treatment and/or use. The concentration of chemical oxygen demand (COD) from the tofu processing industries of Banda Aceh city is ranging from 5000-8500 mg/L, indicated that the waste has potential for bio energy production. About 128.52 m^3/day of CH_4 could be produced from 10 tofu processing industries in Banda Aceh.

Keywords: Renewable energy, Tofu waste, Anaerobic digestion, Environment, Banda aceh, Methane.

INTRODUCTION

Renewable bio-energy from food processing waste (organic wastes) is seen as one of the key options to fossil fuels substitute and mitigates greenhouse gas (GHG) emissions. The biomass contains carbon for renewable energy resource does not lead to the increment of green house CO_2 in a long term and it is expected to be the resource of energy and chemicals in the future. The unrestricted use of fossil fuels-based energy has severely hampered our environment and caused global warming and greenhouse effect. Now, the decreasing availability of fossil fuels has drastically raised the prices of liquid and gaseous fuels worldwide. Therefore, developing renewable energy is indispensable. Anaerobic fermentation technology showed great potential for biogas (hydrogen and methane) and alcohol (bioethanol and biobutanol) production. These biofuels could be converted into energy through combustion engine or fuel cell[1,2]. Among all carriers of renewable energy, biogas (H_2 and CH_4) is an ideal and clean source of energy and its research is becoming more and more popular in recent years due to several benefits to its credit[1,3]. On the other hand, ethanol has remained the major commercial biofuel around the world and is blended with gasoline in several countries. However, production of biohydrogen and ethanol from food based materials crops such as corn and sugarcane is not cost-effective and raised the food and fuel competition issue[3,4]. Therefore, organic wastewaters generated from food and agro-based industries become are a potential feedstock for those renewable energy production.

One of the interest wastewater is tofu processing waste, which contain very high organic carbon. Tofu is a very popular food in Indonesia, due to the associated health benefits and its acceptable price. Tofu produced by grinding of soy bean, cooking (boiling), filtration, protein coagulation, preservation and packaging. Although the tofu industries discharge a lot of wastes, only a small percentage of tofu waste is utilized as nutritious feed for livestock, the remainder being incinerated and/or reclaimed as industrial waste, thereby contributing to serious pollution problems.

The management of tofu processing waste represents an economic problem because of the high transportation costs for disposal, treatment and/or use. The concentration of tofu waste thus becomes a necessary first step for its waste management and recovery. In principle one could use evaporation as concentration process, but unfortunately this can cause damage to heat sensitive components or loss of volatile compounds, so that alternative concentration processes are needed[5]. Owing to its non-cellulosic nature with high carbohydrate and proteins, tofu processing wastewater has the potential to produce renewable energy such as methane, biohydrogen and ethanol. This paper discusses the potential renewable energy from tofu processing waste in a small city, Banda Aceh. The material balance and characteristics of generated tofu waste are also presented.

EXPERIMENTAL

In this study, we conduct on site investigation for analyzing of material flow analysis of tofu production, since the process might differ from other countries. Tofu processing wastewaters were obtained from local tofu factories in Banda Aceh city. Five representative samples from tofu industries were analyzed for their physical and chemical properties.

RESULTS AND DISCUSSION

Banda Aceh is a capital city of Aceh province, located on the tip of Sumatra island, Indonesia. The population of the city is about 240,855 people on the area of 61,359 Ha. The city which has destroyed due to tsunami in 2004 is now recovered with modern facilities. Although the city is low of natural resources, food and agro industrial industries are well developed, as a consequent of high population growth. However development of such industries is not accompanying with waste management strategies.

Characteristic of tofu waste at Banda Aceh city: Five representative tofu-processing waste samples were analyzed for their physical and chemical properties. Table-1 shows the analyses results. The results indicated that the composition and high concentration of proteins, carbohydrate and nitrogenous compounds are found in tofu-processing waste. Therefore it can be reused for biotechnological means. Tofu-processing waste is considered as one of the most polluting food-industrial effluent due to its high values of COD and BOD. The COD of wastewater from tofu processing industries in Banda Aceh is ranging from 5000-8500 mg/L. Such a high concentration of organic compound can cause considerable environmental problem if discharge into the environment without effective treatment. Tofu-processing waste is acidic (pH about 4-5) since during the tofu preparation acetic acid as added for coagulation. There are no hazardous chemical added to tofu during the production process make the tofu waste basically is non toxic, thus can be effective treated biologically. However, without any treatment, bad smell appear after 2 days, due to the degradation of ammonia compounds.

TABLE-1
TOFU EFFLUENT CHARACTERISTIC FROM VARIOUS TOFU INDUSTRIES IN BANDA ACEH

Tofu factory	Parameter		
	COD (mg/L)	pH	Turbidity (NTU)
Tahu Lampaseh Aceh	6500	4.90 (28.6 °C)	387
Tahu Solo	8500	4.85 (28.9 °C)	841
Tahu MKS	7300	4.82 (28.2 °C)	902
Tahu Sumedang	5000	5.50 (28.5 °C)	730
Meurah Jaya	6400	5.08 (28.4 °C)	921

Distribution of tofu processing industries in Banda Aceh: There are 10 tofu processing industries in Banda Aceh with raw materials capacity ranging from 150-500 kg/day for each industry.

Data from statistic office showed that in 2011, there are 14 tofu industries in Banda Aceh. However some industries were closed due to the high price of raw material reason. Survey results in 2013 shows that, there are 10 tofu processing industries in Banda Aceh, distributed on the city. Table-2 shows the detail information about tofu production in Banda Aceh city.

TABLE-2
TOFU PRODUCTION IN BANDA ACEH CITY

Tofu industries	Raw material (kg/day)	Tofu production (kg/day)	Steam required (L/day)	Wood for fuel (Kg/day)	Acid required (L/day)	Number of workers
Tahu Aceh	150	180	250	500	15-20	3
Tahu Solo	500	540	1500	1000	20-30	6
Tahu Mandiri	200	180	500	500	20-30	3
Tahu Sumedang	450	450	1200	1000	15-25	7
Tahu Ayam Jago	150	162	600	500	15-20	3
Tahu MKS	300	240	660	700	15-20	4
Tahu Meurah Jaya	200	180	600	600	15-20	6
Tahu Wahidin	300	270	1000	700	20-25	4
Tahu Lampaseh Aceh	150	180	500	400	20-30	3
Tahu Jamaluddin	150	180	250	500	15-20	3

Material balance of tofu processing: The raw materials for tofu production were obtained from other cities, since Banda Aceh does not produce a soybean. Therefore the price of tofu in Banda Aceh is a little expensive compare to other cities in Indonesia. The efficiency of tofu production are differ each other. Some industries could obtain good results with high productivity. During the production, significant amount of firewood is used for steam preparation, which affect the availability of forest biomass. Thus, alternative fuel should be sought to overcome this matter.

The process for tofu preparation is almost the same in all industries. However the process efficiency a little bit different. A typical process consists of soy bean grinding, cooking (boiling), first filtering, protein coagulation of protein, second filtering, preserving, washing, drying and packaging. The first filtration removes the residues of soy bean from the colloid solution with coarse cloth. The liquid used to coagulate tofu liquor is acetic acid solution (vinegar). The second filtration separates the liquid whey from the soy bean curd. This filtrate becomes wastewater that requires further treatment.

In the case of Aceh Tofu, the industry produces 60 boards tofu/day. Every board tofu has a weight of about 3 kg, so that the production of tofu in a day is 180 kg. Fifteen litres of vinegar is diluted with water to the total amount of 200 L vinegar stock solution. About 15-20 L of vinegar stock is then used for coagulation of 3 tofu board (9 kg). The amount of coagulation solution is depending on the tofu liquor temperature. The higher temperature the more vinegar solution is required for coagulation. About 30 % of used vinegar could be used again for next coagulation process, while the remaining becomes waste and directly dumped into the environment. The fresh water used for steam preparation is 500 L for 20 times of cooking processing. By using firewood as a fuel, the soybean cooking time is about 30-40 min and the firewood needed is approximately 0.5 ton/day.

Totally, about 50,700 kg of waste (*i.e.*, solid waste: 4,800 kg and liquid waste: 45,900 kg) generated from 2,550 kg/day soybean in Banda Aceh. Fig. 1 shows the materials balance of

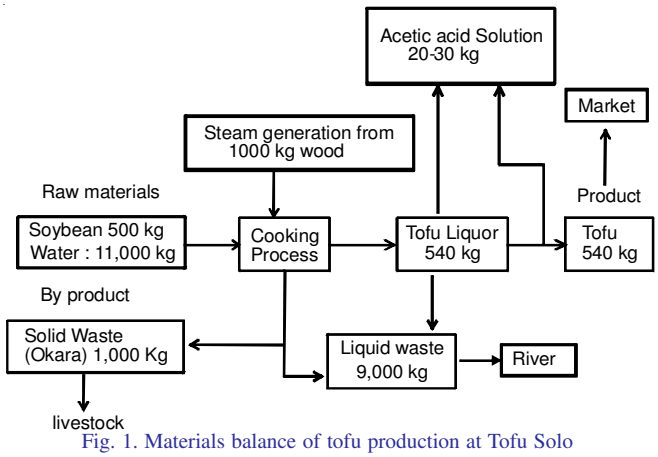

Fig. 1. Materials balance of tofu production at Tofu Solo

Tofu Solo, the biggest tofu processing in Banda Aceh. This factory produces about 540 kg/day tofu from 500 kg of soybean. The by product of solid waste (okara) is sold for animal feedstock. The materials balance of tofu production in Banda Aceh city can be seen in Fig. 2. Visit results shows that, all the tofu processing waste in Banda Aceh city has been disposed into the environment and river without any treatment, causing bad odours and pollution of the surface and ground water. The industries do not treat their waste is due to the high cost of treatment processing.

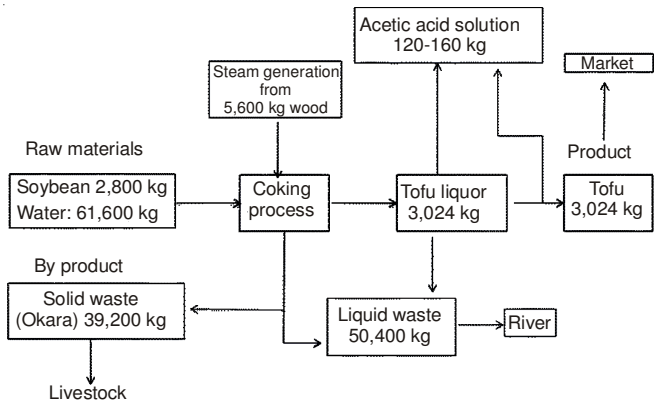

Fig. 2. Materials balance of tofu production in Banda Aceh

The production of tofu requires large amounts of wastewaters, as it is a water intensive process. The wastewater is a serious environmental pollutant due to its high organic content comprising mainly of reducing sugars, sucrose, starch and volatile fatty acids[5]. Although the waste contains oligosaccharides, proteins and isoflavones, which can be isolated and used as ingredients for functional products, it is currently disposed as a waste stream. Unfortunately, when disposed directly to the environment tofu waste can cause bad odours and pollution of the surface and ground water[5-7].

Previous studies have shown that the tofu waste produced biohydrogen through dark and photo fermentation methods[8-11]. It is found that the method not only provide the energy source but also solve the waste treatment problems. Therefore, dual benefits are obtained from fermentation of tofu-processing wastewater, thereby making the process more economical and valuable. Although tofu-processing wastewater to biohydrogen conversion is feasible through fermentation, the process however is still in its infancy and needs to be optimized and appropriate conditions for maximal recovery of biohydrogen should be developed. Process factors such as temperature, pH, nutrient, toxic materials, hydraulic retention time and cell density generally affect the anaerobic fermentation pathway[5].

Renewable energy from tofu processing waste: The wastewater generate from tofu processing waste is usually treated by biological degradation. It is, however, often prohibitively expensive in densely populated areas to the high space requirement of this method. Chemical coagulation is an option to remove most of the organics from the water colloids[12]. The treatment of tofu waste using supersonic irradiation of the substrate suspension on the methane fermentation performance has been studied and found that the supersonic wave irradiation is effective to enhancing the methane yield[13].

Anaerobic digestion of tofu waste producing methane and carbon dioxide and at the same time reducing organic content in the waste. Several process have been developed for effective anaerobic digestion of tofu waste including the upflow anaerobic filter process (UAFP), upflow anaerobic sludge blanket (UASB), anaerobic attached film expanded bed reactor (AAFEB) and anaerobic fluidized bed reactor (AFBR) to improve cell retention and the two-phase digestion process to optimize acidogenesis and methanogenesis. However, to enhance these processes, it is necessary to determine their applicability to other types of wastewater, such as those containing recalcitrant and toxic compounds and high solid organic materials[14]. Digestion thermophilic and under anaerobic conditions is of wide interest for many researchers as a method to treat organic wastes due to its potential to increase biogas production and facilitate pathogen reduction[15]. High rate of methane gas was produce from municipal solid waste at 55 °C[16].

As mention, there is no treatment processing in the tofu manufacturing in Banda Aceh city due to economic reason. In fact, the utilization of tofu waste can produce renewable energy that can use in their industry. The management of tofu waste is very important to be socialized for tofu manufacturing owner. Government involvement is also very necessary to encourage the owner to treat their waste and keep the environment clean. Fig. 3 shows a possible option to manage the tofu waste in Banda Aceh City[17]. The tofu processing waste is digested in anaerobic conditions producing biogas. The biogas is then purified with common technologies to obtain methane for power generation, vehicle and other purposes. The byproduct of anaerobic digestion would be treated for compost for further use in agricultural applications.

Lay *et al.*[1] have studied the bio energy production from tofu-processing wastewater by anaerobic hydrogen fermentation for onsite energy recovery and significant amount of biogas could be produced. Theoretically, 1 kg of COD will produce 0.35 m^3 methane and this value might be used for engineering purposes in the designing & optimization stage of the biogas plant. It is found that the methane yield increases with the increasing substrate loading rate, reaches a maximum and then decreases with a further increasing loading rate. Methane gas are odorless, colorless and highly flammable. Table-3 shows the amount of wastes from tofu processing industries and their possible CH_4 production at Banda Aceh

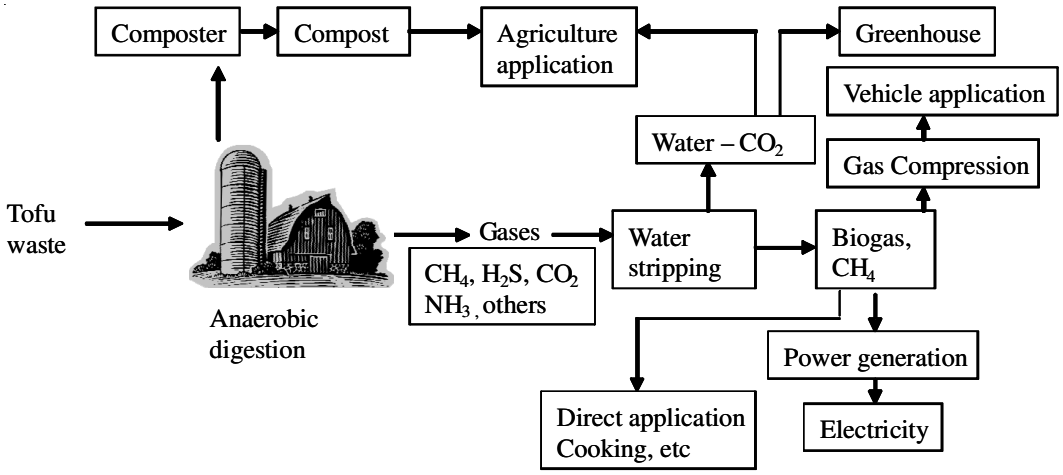

Fig. 3. Management of tofu waste producing for energy recovery and agriculture application (*adopted from ref 15)

city. Based on Table-3, about 128.52 m^3/day of CH_4 could be obtained from 10 tofu processing industries at Banda Aceh. If the CH_4 can be generated every day, about 46,909 m^3/day of CH_4 can be produced in a year. Such a significant amount is equal to 48,410 L diesel fuel per year. The biogas methane is then can be upgraded as well for transportation fuel and thus enhances its economic value in renewable energy market. It should be noted that the biogas obtained from an aerobic digestion of tofu processing waste should be upgraded to meet the basic requirement of fuel. Common technologies available for biogas upgrading include: water scrubbing, pressure swing adsorption (PSA) using molecular sieves and membrane separation[18].

TABLE-3
AMOUNT OF WASTES FROM TOFU PROCESSING INDUSTRIES AND THEIR POSSIBLE CH_4 PRODUCTION AT BANDA ACEH CITY

Tofu Industries	Raw material (kg/day)	Solid waste, Okara (kg/day)	Liquid waste (L/day)	COD /day, Kg	Possible CH_4 production (m^3/day)
Tahu Aceh	150	300	2700	21.6	7.56
Tahu Solo	500	1000	9000	72	25.2
Tahu Mandiri	200	400	3600	28.8	10.08
Tahu Sumedang	450	900	8100	64.8	22.68
Tahu Ayam Jago	150	300	2700	21.6	7.56
Tahu MKS	300	600	5400	43.2	15.12
Tahu Meurah Jaya	200	400	3600	28.8	10.08
Tahu Wahidin	300	300	5400	43.2	15.12
Tahu Lampaseh Aceh	150	300	2700	21.6	7.56
Tahu Jamaluddin	150	300	2700	21.6	7.56
Total	2550	4800	45900	367.2	128.52

Conclusion

About 45,900 kg/day of wastewater produced from 2,550 kg soybean in Banda Aceh. This high amount of waste could disturb the environment and thus further treating process is required. Depend on the process conditions, anaerobic digestion has been suggested as an alternative method of removing the high-concentration organic waste in tofu processing and at the same time can produce a clean renewable energy source of methane and hydrogen. It was necessary to find a renewable and environmentally friendly alternative energy and chemical sources since an environmental pollution occurs due to the use of fossil fuel as well their limitation sources. Tofu processing waste is one alternative to overcome the problem. Investigation results showed that about 128.52 m^3/day of CH_4 could be produce from 10 tofu factories in Banda Aceh. Moreover, the Government involvement is also necessary to encourage the owner to manage the tofu waste.

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REFERENCES

1. C.H. Lay, B. Sen, S.C. Huang, C.C. Chen and C.Y. Lin, *Renew. Energy*, **58**, 60 (2013).
2. L. Appels, J. Lauwers, J. Degrève, L. Helsen, B. Lievens, K. Willems, J. Van Impe and R. Dewil, *Renew. Sustain. Energy Rev.*, **15**, 4295 (2011).
3. L.B. Brentner, J. Peccia and J.B. Zimmerman, *Environ. Sci. Technol.*, **44**, 2243 (2010).
4. M.L. Chong, V. Sabaratnam, Y. Shirai and M.A. Hassan, *Int. J. Hydrogen Energy*, **34**, 3277 (2009).
5. F. Belén, J. Sánchez, E. Hernández, J.M. Auleda and M. Raventós, *J. Food Eng.*, **110**, 364 (2012).
6. A.S. Pablo and R.W. Jorge, *Información Tecnológica*, **20**, 65 (2009).
7. Y. Sudiyani, A. Syarifah, A. Yulia and A. Indri Badria, International Conference on Chemical Sciences (ICCS-2007), ANL/47-6 (2007).
8. H. Zhu, S. Ueda, Y. Asada and J. Miyake, *Int. J. Hydrogen Energy*, **27**, 1349 (2002).
9. G.H. Zheng, L. Wang and Z.H. Kang, *Renew. Energy*, **35**, 2910 (2010).
10. M.-S. Kim and D.-Y. Lee, *Bioresour. Technol.*, **101**, 48 (2010).
11. D.-H. Kim, D.-Y. Lee and M.-S. Kim, *Int. J. Hydrogen Energy*, **36**, 8712 (2011).
12. X. Chai, Y. Mi, P.-L. Yue and G. Chen, *Sep. Purif. Technol.*, **15**, 175 (1999).
13. K. Muroyama, T. Mochizuki and T. Wakamura, *J. Biosci. Bioeng.*, **91**, 208 (2001).
14. N. Nishio and Y. Nakashimada, *J. Biosci. Bioeng.*, **103**, 105 (2007).
15. M.E. Griffin, K.D. McMahon, R.I. Mackie and L. Raskin, *Biotechnol. Bioeng.*, **57**, 342 (1998).
16. S. Suwannoppadol, G. Ho and R. Cord-Ruwisch, *Bioresour. Technol.*, **102**, 7762 (2011).
17. M. Faisal, I. Machdar, F. Mulana and H. Daimon, In Proceeding of The 7th International Conference of Chemical Engineering on Science and Applications, Banda Aceh, Indonesia, pp. 229-234 (2013).
18. M.K. Lam and K.T. Lee, *Biotechnol. Adv.*, **29**, 124 (2011).