The Optimal Conditions of Saccharification and Fermentation Processes for ethanol production from Bagasse and Economic Feasibility Analysis

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September 2, 2019

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Abstract. Thailand is one of the agricultural countries as a good natural resource like rice, sugarcane. The residue of sugarcane is a Bagasse as the main agricultural products of the sugar industry. Since Thailand is one of the major sugar exporters, it is reported that Thailand produces sugarcane bagasse over 50 million metric tons every year. The objective of this research was to study the optimal condition of saccharification and fermentation Bagasse converted to ethanol production. The research found that 7 days after saccharification and fermentation from *Aspergillus* and yeast has the highest ethanol content was 12.45±0.43%. While reducing sugar contents 285.65±0.74 g/L. And the results of ethanol concentration from the first and the second distillation were shown as 65.29±0.57% and 92.05±1.24%, respectively. When a study of economic feasibility analysis from selected ethanol condition process has a sensitivity analysis and the payback period is approximately only five months to seven months. In conclusion, the proposed project is attractive for the investors because the current price of ethanol is 18.21 THB per litter and its trend is expected to keep rising. However, if sugarcane bagasse was properly managed, it would be mean to support the robustness and sustainability of the community. It can also reduce agricultural waste and weeds. It can solve the energy crisis as an alternative avenue in the future.

1. Introduction

Nowadays, countries are supporting and developing more renewable energy. The reduce proportion of dependence on energy imports, especially Biofuel can be produced from various agricultural products such as Soybean, Water Hyacinth, Sugarcane, Cassava, Palm oil, and Corn oil etc.[1] Energy is very important to the national economy. Especially in the industrial sector, transportation sector, agriculture and business sectors etc. [2, 4, 7] The allocation of energy is sufficient and has a reasonable price in accordance with the demand. Is something that energy policy makers should act At present, the amount of energy usage is increasing gradually while Thailand still imports a lot of energy from foreign countries.[3, 5] Therefore, to ensure that In the future, Thailand will have enough energy to meet demand. Resulting in the concept of alternative energy development and the use of domestic energy sources to promote the country's energy security Which the energy source should be cheap and large enough For this reason, biomass renewable energy is considered an energy source. It has great potential and potential to be used because Thailand has a lot of leftovers from the agricultural sector. Which are sources of energy that are easy to find and cheap [6,8]

Bagasse is the part of the sugar cane stalk that has been taken out of sugar cane juice or sugar. Nowadays, bagasse can be used for many uses such as the development of autoclaved aerated bricks, biogas, ethanol and others. [9] Ethanol is considered to be the energy that is chosen to replace the oil on the market, whether diesel or benzene. Because ethanol possesses clean fuel. Complete combustion process without lead and can help reduce environmental pollution.[10] The utilization of ethanol can be used in agriculture and industry. In the ethanol production process occurs from the fermentation process using sugar source that has been degraded from waste materials from bagasse. Which bagasse is classified as a raw material with a lower production cost than other raw materials In general, the application of bagasse is usually preferable by combustion. The combustion will directly affect the atmosphere. [3,11] the Causing of greenhouse effect and also the affecting environment as well. This research was to study the optimal condition of saccharification and fermentation Bagasse converted to ethanol production. And a study of economic feasibility analysis from selected ethanol condition process has a sensitivity analysis and the payback period. For a solve the energy crisis as an alternative avenue in the future.

2. Theoretical Background

Sugarcane has the scientific name *Saccharum officinarum* L. It is a plant belonging to the same family POACEAE with bamboo, grass and grains such as wheat, rice, corn and barley.[11] Bagasse is the remnants of the sugar cane trunk that has taken sugar cane juice or sugar from the logs. When the sugar cane passes through the first set of chests, there may be still water left over. But when passing through the foreskin set 3 to 4, there is very little residue Meaning only pure fibers. [12-14] Subsequent by-products are Filter Mud or Filter Cake or Filter Muck, which are filtered or purified by bagasse juice by any means. [15] Is the final by-product cake filter, molasses, which is thick and sticky Dark brown is the part that can be extracted sugar by normal methods. In the past, bagasse was used as a fuel for boiling water in a steam boiler and then using steam power for operating steam engines and for electricity generation, but many bagasse still remain due to not being used. Exhausted causing problems in removal and destruction Although some places are used as distilled liquor or alcohol. But many remaining bagasse. [14, 16] Bagasse consists of two parts: 18% cell texture and 82% cell wall, with 40% cellulose, 29% hemicellulose, 13% lignin and 13% silica. 2 components of the cell wall of rice and sugarcane by-products.[17]

Lignocellulose Is a complex of lignin, hemicellulose, and cellulose, a component of plant cell walls And classified as dietary fiber insoluble in water in different ratios depending on the type of lignocellulose material Generally, 40-60 percent cellulose is found, 20-30 percent hemicellulose and 15-30 percent lignin.[18] The Cellulose is a component found in lignocellulose materials, found in the cell wall of plants, combined with hemicellulose and lignin. [18] The amount of the substance varies depending on the type and part of the plant, for example. Wood is found in 40-50 percent and cotton fibers are around 98 percent. Cellulose is a homopolymer, characterized by a straight line without branches, consisting of sub-units, beta-D-glucopropanol (β -D -Glucopyranose) Connection with the β -1,4-glycosidic bond is formed as a glucan polymer with a natural length of approximately 10,000 units bonded with hydrogen bonds.[17, 19] In general, two types of cellulose is crystalline. cellulose and amorphous cellulose. The crystalline cellulose is degraded by enzymes more difficult than amorphous cellulose as shown in Fig. 1[18, 20]

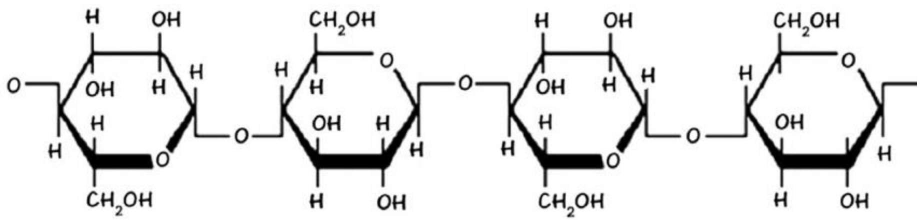

Figure. 1 Cellulose Structure

Hemicellulose, one of the components in lignocellulose materials, is a heteropolymers of many different types of sugars, such as glucose, mannose, xylose and aromatic. In the form of polymers, xylan, man-galactanate and Arabinan, the average length is about 200 units, with the highest Vylan-Xylose polymer being 85-93 percent. Such as glucose, glucose acid Galacturonic acid is found in small amounts, with the xylose being bonded with beta 1,4-glycosidic bonds for the chemical structure of xylan hemicellulose in plants found in plant tissues. It is combined with other substances such as lignin. Cellulose is the structure of the cell wall. Chemical formula is $(C_6H_{12}O_5)$ 2n. Hemicellulose is the polymer of the pentose sugar. [18, 19] Most of which are D-xylan which consists of many sugar molecules connected by bonds 1-4-glucosidic Hemicellulose polymer cables have the characteristics of heterogeneous It consists of many types of polysaccharides, which are mainly pentosans, silansans and arabs. When digested, the sugar was obtained. And arabicosilan is a substance that is contained in hemicellulose than other substances as shown in Fig. 2 [20]

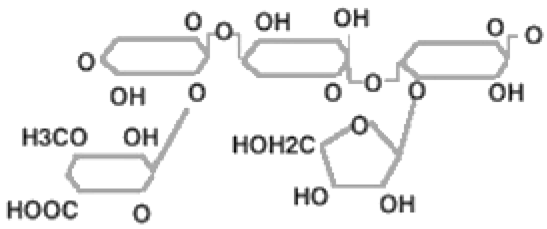

Figure 2 Hemicellulose Structure

Lignin is an aromatic compound known as Phenolic polymers, in which the -Ogroup can bond with the aldehyde group as hemiacetal and the ketone group as ketal, with randomly connected phenyl propane units At the phenol unit it may be guaiacyl or saringyl at the alpha and beta positions of the lignin molecule. There may be a link between molecules or carbon in the phenolic unit. Bonds may be formed in another unit within the polymer chain that composes the lignin molecules. Resulting in lignin having a strong structure, insoluble in water, but able to dissolve in some organic solvents such as ethanol or hot methanol And sodium hydroxide solution Lignin is usually found in the structure of plant cells around cellulose. [21] As a cellulose protector from digestion as well Lignin is resistant to microbes and anaerobic process in which microbes are not able to react with the aromatic ring of lignin or if able to react, it will be very slow for a time. Several days Lignin is found in nature as a binder between cellulose and hemicellulose. Most of them are found in the cell walls of plants which have different amounts according to the type of plants in nature. Lignin protects cellulose from being easily digested by enzymes of micro-lignin. [22] Is a heteropolymer with 3-dimensional crystallization structure consisting of 3 aromatic compounds consisting of tran-p-coumaryl alcohol, trans-coniferyl alcohool and trans-p-sinapyl alcohol. In addition, lignin molecules are connected to many other aromatic compounds such as vanillin and syringaldehyde. Structural formula of tran-p-coumaryl alcohol, trans-coniferyl alcohool and trans-p-sinapyl alcohol as shown in Fig. 3 [20, 23]

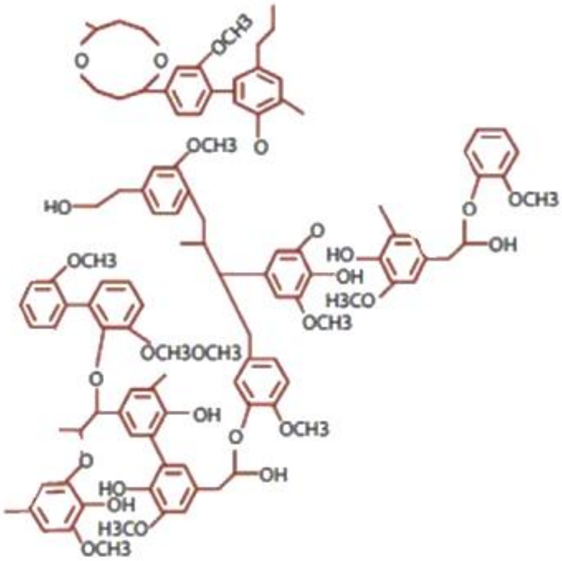

Figure 3 lignin Structure

The Pretreatment of lignocellulose into raw materials consisting of natural fibers, cellulose, hemicellulose-cellulose, lignin and other substances. Raw material preparation must be done in two processes. Is the pretreatment and hydrolysis, which in this pretreatment process will reduce hemicellulose and lignin to the maximum cellulose. It also helps to reduce the crystallization of cells. And increase porosity in the raw material Resulting in a better effect on the hydrolysis process for enzymatic digestion In addition, pretreatment requires the improvement of sugar structure, helping to avoid the deterioration of carbohydrates in raw materials. And reducing the production of inhibitors that will interfere with the enzyme activity. as shown in Fig. 4 [20, 24]

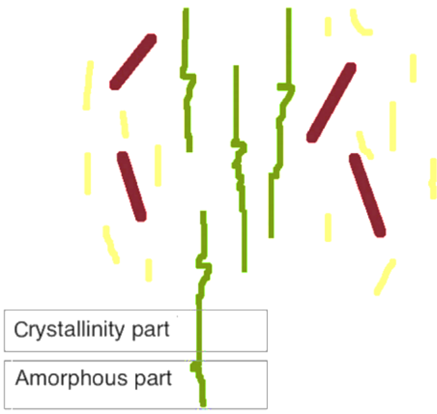

Figure 3 Pretreatment of lignocellulose Structure

Ethanol fermentation, In most cases, yeast is used to change glucose. Or fructose sugar Into alcohol and with carbon dioxide by-products As the equation below In theory, alcohol is about 50% of the amount of sugar used. But in practice it is often not due to the production of many different flavoring substances. as shown in Fig. 3 [25] Therefore, if fermenting sugar with a sugar content of 20 ° Briggs or 200 grams per liter, we should get about 100 grams of alcohol per liter or 10 percent or less a bit. Because waste is a by-product, but when calculated as a percentage by volume, we need to use the alcohol specific gravity to calculate 0.7893, resulting in an increased alcohol content of more than 10 percent. For example, if having 96.3 grams of alcohol per liter, it will get 12.2 percent by volume. (9.63 divided 0.7893) in the yeast fermentation will grow Rapidly during the first 2-3 days, after which the growth will slow down until the number does not increase, but in this period Still increasing the amount of alcohol And the amount of sugar decreased And creating various flavoring substances During this period, so must continue to ferment Even though the yeast has stopped growing [23, 26-28]

3. Methods

3.1 Bagasse Preparation

The bagasse are cut to 1-2 centimeters in size, reduce the humidity by drying in the sun for 2 days, then drying at 80 degrees Celsius for 8 hours, then grinded with an ultra centrifugal mill and sorted. Particle size by sieve test until the bagasse size is obtained 500 micrometers by placing in closed container at room temperature. [22, 29] The components were analyzed using Detergent method, Neutral detergent fiber (NDF), Acid detergent fiber (ADF) and Acid detergent lignin (ADL) analysis. [28, 30]

3.2 Optimal Condition of Saccharification and Fermentation Bagasse

Bagasse from 3.1 were treated and fermented with *Aspergillus* and *saccharomyces* in different conditions, as shown in Table 1, and then analyzed for Reducing sugar content And The ethanol content [5, 12, 20, 28]

Table 1 The Condition of Saccharification and Fermentation Bagasse

Sampling	**Bagasse (g)**	**Time (day)**	**% of *Aspergillus***	**% Yeast**	**%Water**
1	60	1	5	15	80
2	60	3	5	15	
3	60	7	5	15	
4	60	1	10	10	
5	60	3	10	10	
6	60	7	10	10	
7	60	1	15	5	
8	60	3	15	5	
9	60	7	15	5	
10	120	1	5	15	
11	120	3	5	15	
12	120	7	5	15	
13	120	1	10	10	
14	120	3	10	10	
15	120	7	10	10	
16	120	1	15	5	
17	120	3	15	5	
18	120	7	15	5	

3.3 Economic Feasibility Analysis from Ethanol Production was selected

The best condition of Bagasse Ethanol Production was to selected for economic calculation as Net present value (NPV), Return On Investment(ROI) and Payback Period, It was used from the 1st , 2nd and 3th equations. [27, 31-32]

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+r)^t} \quad \text{[1]}$$

CF = Cash flow
r = Required rate of return
t = year of cash flow
N = the n^{th} year

Return On Investment= ((Discounted Benefits Discounted Costs))/(DiscountedCosts)…………...…[2]
Payback Period = Number of years prior to full recovery+((Unrecovered cost at start of year)/(Cash flow during full recovery year))…………………………………………………….…...…….[3]

4. Results and Discussion

The study of the optimum conditions for ethanol production from bagasse found that the physical characteristics of bagasse after being exposed to the sun to expel moisture from the light yellow appearance, as shown in Figure 4. When studying the composition of bagasse, the highest amount of cellulose was 45.35, followed by hemicellulose 32.54 and lignin equal to 5.96 percent respectively, as shown in Figure *5*.

Figure 4 Bagasse from Yala Province, Thailand

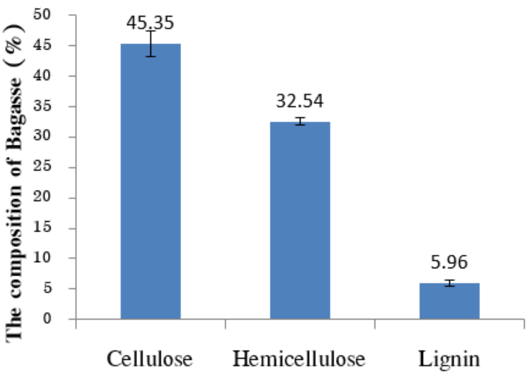

Figure 5 The lignocellulosic composition of Bagasse

When the samples were taken to study the optimum conditions according to Table 1, it was found that the amount of ethanol Which using 60 grams of bagasse mixed with aspergillus at 15 percent and yeast at 5 percent at a 7 day fermentation time of 12.45 percent and with reducing sugar content of *285.65* grams per liter as follows Shown in pictures 6 and 7

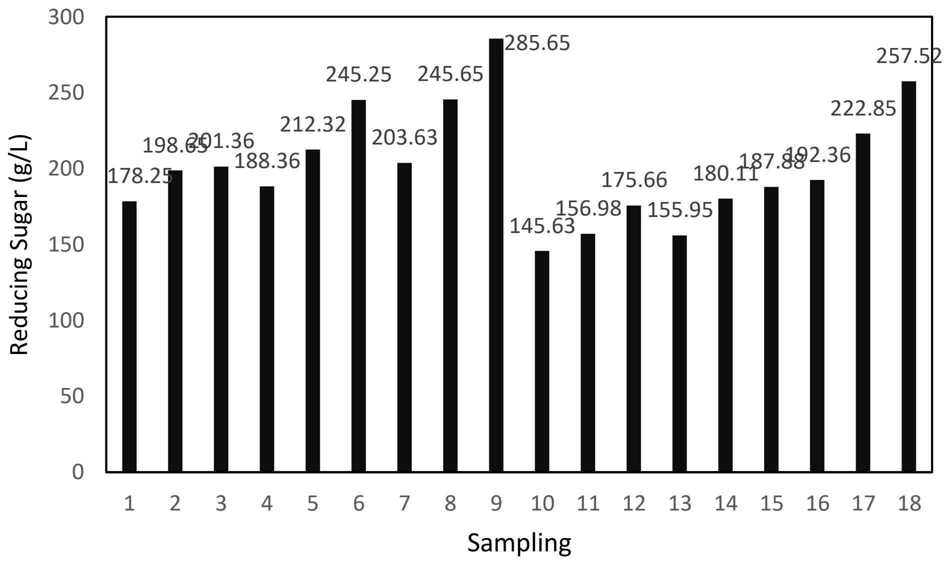

Figure 6 Reducing sugar content of Condition of Saccharification and Fermentation Bagasse

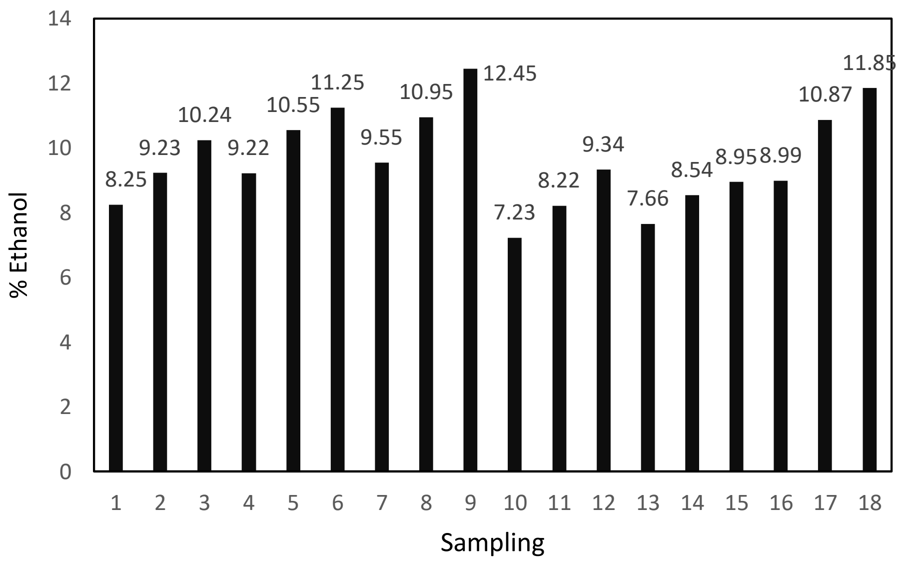

Figure 7 The percent ethanol content of Condition of Saccharification and Fermentation Bagasse

When the optimum conditions were used to distilate 2 rounds then analysed with Gas Chromatography Graph found that The first ethanol distillation cycle was 65.29 and the second distillation was 92.05 percent, respectively. As shown in picture 8

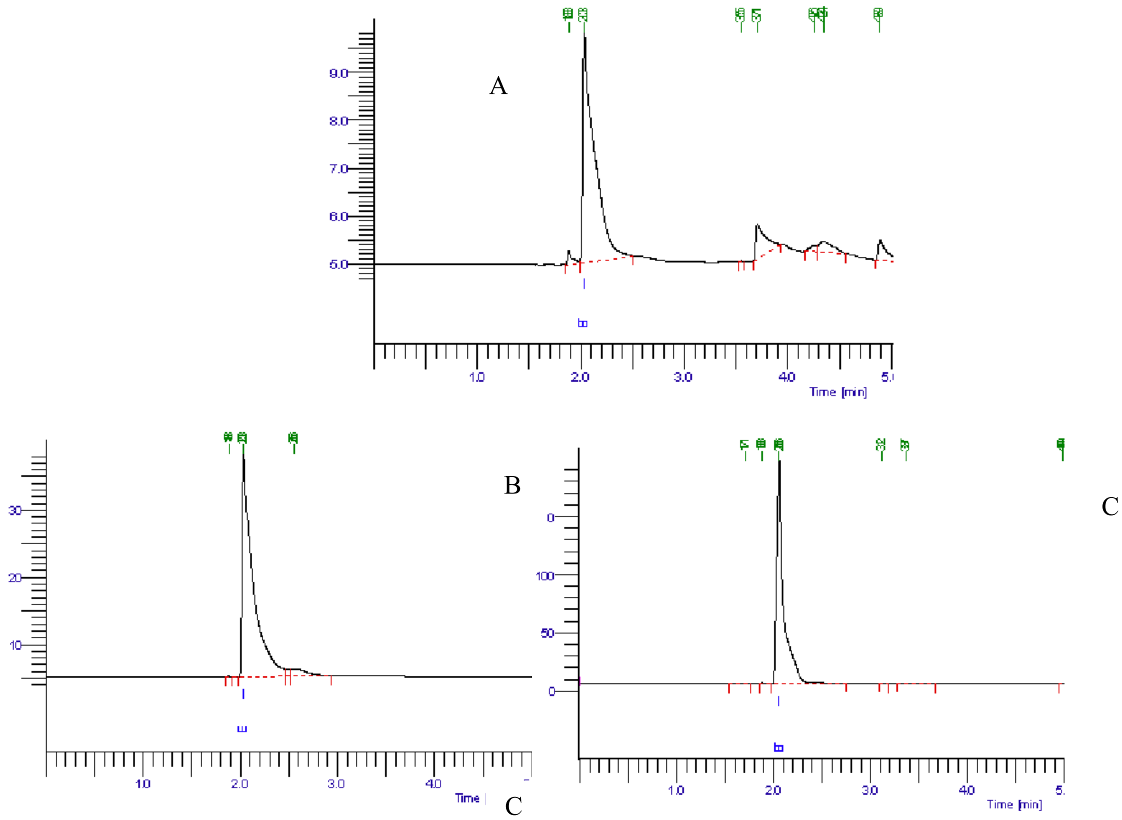

Figure 8 The amount of ethanol that h en analyzed by gas chromatography, where A is 12.45 percentage of the amount of ethanol obtained from fermentation gave, B is 65.29 percentage of the amount of the first distilled ethanol and C is 95.05 percentage of the amount 2nd ethanol distilled

When a study of economic feasibility analysis from selected ethanol condition process has a sensitivity analysis and the payback period is approximately only five months to seven months. In conclusion, the proposed project is attractive for the investors because the current price of ethanol is 18.21 THB per litter and its trend is expected to keep rising. By using the initial cost of investment equal to 99,050 baht, divided into expenses such as *Bagasse*, *Aspegillus* sp, S. cerevisiae yeast, plastic bucket , water filter, Distiller , Sodium meta-bisulfite (Na*2*S*2*O*5)* etc. , As shown in Table 2

Table 2 The cost of ethanol production from bagasse with *Aspergillus* and *S. Cerevisiae* yeast compared per year.

Item	Unit	Cost(Bath)
Bagasse	100 kilogram	200
Aspegillus sp	1 strain	400
S. cerevisiae yeast	1 Strain	400
Plastic bucket	30 Bottle	900
water filter	1	12,000
Distiller	1	80,000
Sodium meta-bisulfite ($Na_2S_2O_5$)	1 kilogram	150
Other	-	5,000
	Total	99,050

5. Conclusion

The optimal condition of saccharification and fermentation Bagasse converted to ethanol production. It was found that 7 days after saccharification and fermentation from *Aspergillus* and yeast has the highest ethanol content gave 12.45±0.43%. While reducing sugar contents gave 285.65±0.74 g/L. And the results of ethanol concentration from the first and the second distillation were shown as 65.29±0.57% and 92.05±1.24%, respectively. When a study of economic feasibility analysis from selected ethanol condition process has a sensitivity analysis and the payback period is approximately only five months to seven months. In conclusion, the proposed project is attractive for the investors because the current price of ethanol is 18.21 THB per litter and its trend is expected to keep rising.

Acknowledgements

The authors would like to thank for supporting chemical and instrument in this research by Renewable Research Unit, Program of Renewable Energy Technology, Faculty of Science Technology and Agriculture, Rajabhat Yala University, Thailand; and Energy Laboratory, Program of Biotechnology, Faculty of Agro-industry, Rajamangala University of Technology Srivijaya, Thailand.

References

[1] G.M. Campbell, N. Čukelj Mustač, M. Alyassin, L.D. Gomez, R. Simister, J. Flint, D.J. Philips, M.J. Gronnow, N.J. "Westwood, Integrated processing of sugarcane bagasse: Arabinoxylan extraction integrated with ethanol production", Biochemical Engineering Journal, 146 (2019) 31-40.

[2] Z. Wang, B.S. Dien, K.D. Rausch, M.E. Tumbleson, V. Singh, "Improving ethanol yields with deacetylated and two-stage pretreated corn stover and sugarcane bagasse by blending commercial xylose-fermenting and wild type Saccharomyces yeast", Bioresource Technology, 282 (2019) 103-109.

[3] J.K. Gore-Langton, L.P. Spear, "Prenatal ethanol exposure attenuates sensitivity to the aversive effects of ethanol in adolescence and increases adult preference for a 5% ethanol solution in males, but not females", Alcohol, 79 (2019) 59-69.

[4] S. Feng, R. Wei, M. Leitch, C.C. Xu, "Comparative study on lignocellulose liquefaction in water, ethanol, and water/ethanol mixture: Roles of ethanol and water", Energy, 155 (2018) 234-241.

[5] T.S. Moraes, H.N. Cozendey da Silva, L.P. Zotes, L.V. Mattos, L.E. Pizarro Borges, R. Farrauto, F.B. Noronha, "A techno-economic evaluation of the hydrogen production for energy generation using an ethanol fuel processor", International Journal of Hydrogen Energy, 44 (2019) 21205-21219.

[6] Y. Xu, D. Wang, "Integrating starchy substrate into cellulosic ethanol production to boost ethanol titers and yields", Applied Energy, 195 (2017) 196-203.

[7] B.d.S. Renato, E.V.R. Castro, A. Teixeira, R.R.T. Rodrigues, N.d.S. Renato, "Effects of ethanol on the performance of kinetic hydrate inhibitors", Fluid Phase Equilibria, 476 (2018) 112-117.

[8] S.M. Mooney, E.I. Varlinskaya, "Enhanced sensitivity to socially facilitating and anxiolytic effects of ethanol in adolescent Sprague Dawley rats following acute prenatal ethanol exposure", Alcohol, 69 (2018) 25-32.

[9] P.W. Czoty, W.S. John, A.H. Newman, M.A. Nader, "Yawning elicited by intravenous ethanol in rhesus monkeys with experience self-administering cocaine and ethanol: Involvement of dopamine D3 receptors", Alcohol, 69 (2018) 1-5.

[10] A. Nikolaidis, T. Moschakis, "On the reversibility of ethanol-induced whey protein denaturation", Food Hydrocolloids, 84 (2018) 389-395.

[11] R. Singh, F. Kemausuor, M. Wooldridge, "Locational analysis of cellulosic ethanol production and distribution infrastructure for the transportation sector in Ghana", Renewable and Sustainable Energy Reviews, 98 (2018) 393-406.

[12] L. Marrodán, Á.J. Arnal, Á. Millera, R. Bilbao, M.U. Alzueta, “High-pressure ethanol oxidation and its interaction with NO”, Fuel, 223 (2018) 394-400.
[13] M.A. Bahmani, M. Shafiei, K. Karimi, “Anaerobic digestion as a pretreatment to enhance ethanol yield from lignocelluloses”, Process Biochemistry, 51 (2016) 1256-1263.
[14] S. Parsons, M.C. McManus, C.M. Taylor, “Chapter 13 - Second-Generation Ethanol from Lignocellulose’, in: P. Thornley, P. Adams (Eds.) Greenhouse Gas Balances of Bioenergy Systems, Academic Press, Place Published, 2018, pp. 193-206.
[15] A.K. Chandel, V.K. Garlapati, A.K. Singh, F.A.F. Antunes, S.S. da Silva, “The path forward for lignocellulose biorefineries: Bottlenecks”, solutions, and perspective on commercialization, Bioresource Technology, 264 (2018) 370-381.
[16] J. Xia, Y. Yang, C.-G. Liu, S. Yang, F.-W. Bai, “Engineering *Zymomonas mobilis* for Robust Cellulosic Ethanol Production”, Trends in Biotechnology, 37 (2019) 960-972.
[17] N.W. Burman, C.M. Sheridan, K.G. Harding, “Lignocellulosic bioethanol production from grasses pre-treated with acid mine drainage: Modeling and comparison of SHF and SSF”, Bioresource Technology Reports, 7 (2019) 100299.
[18] R.K. Prasad, S. Chatterjee, P.B. Mazumder, S.K. Gupta, S. Sharma, M.G. Vairale, S. Datta, S.K. Dwivedi, D.K. Gupta, “Bioethanol production from waste lignocelluloses: A review on microbial degradation potential, Chemosphere”, 231 (2019) 588-606.
[19] N. Akhtar, D. Goyal, A. Goyal, “Characterization of microwave-alkali-acid pre-treated rice straw for optimization of ethanol production via simultaneous saccharification and fermentation (SSF)”, Energy Conversion and Management, 141 (2017) 133-144.
[20] F. Ghaemi, L.C. Abdullah, H. Ariffin, “Chapter 2 - Lignocellulose Structure and the Effect on Nanocellulose Production”, in: H. Ariffin, S.M. Sapuan, M.A. Hassan (Eds.) Lignocellulose for Future Bioeconomy, Elsevier, Place Published, 2019, pp. 17-30.
[21] A. Sotiropoulos, I. Vourka, A. Erotokritou, J. Novakovic, V. Panaretou, S. Vakalis, T. Thanos, K. Moustakas, D. Malamis, “Combination of decentralized waste drying and SSF techniques for household biowaste minimization and ethanol production”, Waste Management, 52 (2016) 353-359.
[22] I. Loaces, S. Schein, F. Noya, “Ethanol production by Escherichia coli from Arundo donax biomass under SSF, SHF or CBP process configurations and in situ production of a multifunctional glucanase and xylanase”, Bioresource Technology, 224 (2017) 307-313.
[23] T. Srimachai, V. Thonglimp, S. O-Thong, “Ethanol and Methane Production from Oil Palm Frond by Two Stage SSF”, Energy Procedia, 52 (2014) 352-361.
[24] E.M. de Barros, V.M. Carvalho, T.H.S. Rodrigues, M.V.P. Rocha, L.R.B. “Gonçalves, Comparison of strategies for the simultaneous saccharification and fermentation of cashew apple bagasse using a thermotolerant Kluyveromyces marxianus to enhance cellulosic ethanol production”, Chemical Engineering Journal, 307 (2017) 939-947.
[25] V.d.S. Lopes, J. Fischer, T.M.A. Pinheiro, B.V. Cabral, V.L. Cardoso, U. Coutinho Filho, “Biosurfactant and ethanol co-production using Pseudomonas aeruginosa and Saccharomyces cerevisiae co-cultures and exploded sugarcane bagasse”, Renewable Energy, 109 (2017) 305-310.
[26] F.B. Mendes, D. Ibraim Pires Atala, J.C. Thoméo, “Is cellulase production by solid-state fermentation economically attractive for the second generation ethanol production?”, Renewable Energy, 114 (2017) 525-533.
[27] Y. Liu, J. Xu, Y. Zhang, Z. Yuan, M. He, C. Liang, X. Zhuang, J. Xie, “Sequential bioethanol and biogas production from sugarcane bagasse based on high solids fed-batch SSF”, Energy, 90 (2015) 1199-1205.
[28] D. Dahnum, S.O. Tasum, E. Triwahyuni, M. Nurdin, H. Abimanyu, “Comparison of SHF and SSF Processes Using Enzyme and Dry Yeast for Optimization of Bioethanol Production from Empty Fruit Bunch”, Energy Procedia, 68 (2015) 107-116.
[29] W.-H. Lee, Y.-S. Jin, “Improved ethanol production by engineered *Saccharomyces cerevisiae* expressing a mutated cellobiose transporter during simultaneous saccharification and fermentation”, Journal of Biotechnology, 245 (2017) 1-8.

[30] Z.-H. Liu, H.-Z. Chen, "Two-step size reduction and post-washing of steam exploded corn stover improving simultaneous saccharification and fermentation for ethanol production", Bioresource Technology, 223 (2017) 47-58.
[31] M. Arshad, M. Abbas, M. Iqbal, "Ethanol production from molasses: Environmental and socioeconomic prospects in Pakistan: Feasibility and economic analysis", Environmental Technology & Innovation, 14 (2019) 100317.
[32] T. Xuan Do, H. Prajitno, Y.-I. Lim, J. Kim, "Process modeling and economic analysis for bio-heavy-oil production from sewage sludge using supercritical ethanol and methanol", The Journal of Supercritical Fluids, 150 (2019) 137-146.