Heat Integration and Batch Scheduling of Optimal Bioethanol Production

Pattarawadee Sungpichai and Thongchai R. Srinophakun*

Interdisciplinary of Sustainable Energy and Resources Engineering, Faculty of Engineering, Kasetsart University, 10900 Bangkok, Thailand.

‡Corresponding Author; Thongchai R. Srinophakun, 10900 Bangkok, Thailand,

Tel: +6627970999 ext. 1215, fengtcs@hotmail.com

Received: 21.05.2020 Accepted:01.07.2020

Abstract: This paper examines bioethanol production from oil palm empty fruit bunches, 47,208 kgs of which could potentially produce 13,950 liters of ethanol per day, using the Aspen Plus Suite commercial software. Continuous ethanol production with efficiency, optimum plant design, process dynamics, and control were studied in a continuous process to minimize the loss of plant utility and prevent possible ethanol production failure, which can sometimes occur in real life. A Gantt chart was used for continuous production to obtain ethanol every 24.5 hours. The Gantt chart also increases equipment efficiency by up to 73.90%. Pinch analysis was conducted for minimal energy consumption at the plant. The proposed production without/with the heat exchanger network shows that the total costs per year are 1,343,861$/year and 886,253$/year, respectively. The implementation of a heat exchanger network can reduce costs by around 34.05% per year. The purification process is guaranteed by the controller of the column system due to its dynamic failure sensitivity. Details of the controller and the results in the dynamic mode are presented.

Keywords Bioethanol production; Oil palm empty fruit bunches; Pinch analysis; Gantt chart; Process dynamics; Control

1. Introduction

The global human community is becoming increasingly concerned about global warming and the petroleum crisis. Therefore, finding renewable energy sources is extremely important. Ethanol is an interesting alternative to fossil fuel. The fermentation process can produce ethanol through enzyme catalysis. Biomass resources from a variety of raw materials and can be used with starch and sugar during the fermentation process to produce ethanol. [1] Moreover, consumers concerned about environmental issues will want to know the origin and sustainability of the production process. As a result, the industry must adjust and respond to consumer demand by assessing the life cycle of the product by considering its environmental impact, especially greenhouse gas emissions.

Ethanol is another alternative to gasoline and diesel. It is produced from raw materials containing sugar and starch, although these are limited since they are used in many human staple foods. Today, bioethanol production has increased along with the price of raw materials. Therefore, it is important to find other raw materials to produce ethanol at a lower price which are not used as human staples. The biomass material lignocellulose appears to offer a solution. Many materials are used in the production of ethanol, such as oil palm empty fruit bunches which are outside the human food chain, resulting in these raw materials being cost-effective for ethanol production without conflicting with the human food supply.

Empty fruit bunches are important by-products of biomass production in the palm oil industry. Palm oil waste is a source of lignocellulose and a relatively inexpensive raw material for ethanol production. Empty oil palm fruit bunches have a high fermentation potential, comprising 37.3—46.5% cellulose and 25.3—33.8% hemicellulose [2].

However, since ethanol production is still in the experimental stage, this research involves the production of ethanol at the industrial level through the simulation process using Aspen Plus. The production of ethanol at the industrial level requires continuous production of approximately 10,000 liters per day (the experimental results indicate that 13,950 liters of ethanol can be produced per day). As well as the need for continuous ethanol production, it is important to design an economic, energy-efficient ethanol production plant to ensure no system failures occur during operation, and this requires additional controllers. Therefore, this research focuses on the optimization of ethanol production from palm waste by minimizing energy consumption, scheduling the production process, dynamics, and control. The programs used in this study consist of Aspen Plus, Aspen Batch Process Developer, Aspen Energy Analyzer, and Aspen Plus Dynamics. Aspen Plus provides the conceptual design of the ethanol production process. The Aspen Batch Process Developer then creates the production schedule and proposes the minimum time required to obtain ethanol, while the Aspen Energy Analyzer minimizes energy consumption. Lastly, Aspen Plus Dynamics is used to study the controllability of the process.

2. Process Modeling

There are nine processes involved in bioethanol production from oil palm empty fruit bunches: 1. hot compressed water (HCW); 2. hot water extraction; 3. alkaline hydrogen peroxide; 4. neutralization; 5. mixing; 6. autoclave; 7. simultaneous saccharification and fermentation process (SSF); 8. autoclave; and 9. purification. The pretreatment process contains three sub-processes: hot compressed water (HCW), hot water extraction, and alkaline hydrogen peroxide.

2.1. Simulation of the Bioethanol Production Process from Oil Palm Empty Fruit Bunches Using Aspen Plus

This research examines the bioethanol production process with a capacity of 13,950 liters per day and an ethanol concentration equal to 99.5% wt. The raw material consists of oil palm empty fruit bunches weighing 47,208 kgs per day. In the bioethanol production process, different pretreatments are compared to find the most suitable for producing bioethanol and biomethane from corn, stover, and switchgrass [3]. Therefore, experiments need to be designed to achieve the optimal bioethanol production process. Many previous studies include experiments for the efficient production of bioethanol. There are many relevant reports, such as on the conceptual design of the hydrogen production process from bioethanol reformation [4], design, and optimization of a sono-hybrid process for bioethanol production from Parthenium hysterophorus [5], enhanced production of bioethanol and biodiesel from algae oil via glycerol fermentation [6], and an industrial symbiosis system for improving bioethanol production [7]. Bioethanol production using whole slurry from autohydrolyzed Eucalyptus globulus wood at high-solid loadings has also been studied [8]. From the economic perspective, industrial-scale bioethanol production using brown algae in the pretreatment process has been proposed [9], as well as the modeling and optimization of bioethanol production from breadfruit starch hydrolyzate using response surface methodology and an artificial neural network [10]. The optimization of bioethanol production from glycerol using Escherichia has also been recently investigated [11].

The process of ethanol production using oil palm empty fruit bunches consists of nine steps: 1) Pretreatment with hot compressed water at 200 °C, 30 bar for 15 mins to increase the porosity of the material. 2) Hot water extraction at 80 °C for 30 mins to destroy the hemicellulose. 3) Alkaline H2O2 at 70 °C for 30 mins to extract lignin. 4) Neutralizing with water: the substance is 20:1. 5) Mixing between buffers, consisting of DI, sodium citrate, citric acid, and distillate water, pH 4.8 with a concentration 0.05 M, buffer, the substance is 1:10 (270ml), yeast extract 10g/LBuffer and substance. 6) Autoclave at 121 °C for 20 mins. 7) The SSF process to biochemically change glucose into ethanol. 8) Autoclave again at 121 °C for 20 mins. 9) Purification. In this research, the pervaporation process is used to increase the purity of bioethanol to meet the required statement. The optimum simultaneous saccharification and fermentation incubation time was analyzed using the cellulase enzyme for sugarcane bagasse [12]. The solid-state fermentation (SSF)-derived cellulase for saccharification of the green seaweed Ulva can increase the bioethanol production [13]. The proposed ultrasonic-assisted simultaneous saccharification and fermentation of pretreated oil palm fronds was introduced [14]. Furthermore, ethanol supply chain decisions are essential factors at the industrial scale. For example, ethanol supply chains and economic approaches toward ethanol production have an impact on the optimal design of bioethanol supply chains according to a new European Commission proposal [15]. Integrated decision making to achieve the optimal bioethanol supply chain, and the hierarchical economic potential approach for the techno-economic evaluation of bioethanol production from oil palm empty fruit bunches have also been presented. [16, 17]. The raw material requirement to achieve an ethanol capacity of 13,950 liters per day is shown in Tables 1 and 2.

Table 1. Composition of oil palm empty fruit bunches

S#	1	2
Treatment	Raw material	Hot compressed water
(% Dry weight) Cellulose	38.85(±0.72)	69.27(±0.421)
(% Dry weight) Lignin	11.62(±0.221)	3.77(±0.221)

(% Dry weight) Ash	1.4(±0.121)	1.44(±0.039)
(% Dry weight) Hemicellulose	26.14(±0.11)	8.63(±0.021)

Table 2. Yield and moisture after bioethanol production processes

Process	Yield (% Dry weight)	Moisture (% Wet weight)
Hot compressed water	90.8	37
Hot water extraction	76.9	82
Alkaline hydrogen peroxide	86.6	84
Neutralization	99.7	12

3. Results and Discussion

3.1. Production Schedule Optimization

The Aspen Batch Process Developer model provided the total mass balance during the process and displayed the production sequences. The Gantt chart then displayed the production sequences. Ethanol production can yield 13,950 liters per day, with 24.5 hours between production cycles. The operating time shown in Table 3 assumes that the transfer time between operations is 15 minutes.

Therefore, the batch processing time is approximately 100.67 hours. Considering the subsequent processing modes, batches can be divided into two types. The default non-overlapping mode is used when the previous mode is complete and the overlay mode allows for simultaneous multiple batch processing. [18] The latter can greatly reduce the free time of the device. This research uses the overlap mode due to the reduction of free time.

Table 3. Operation time of each process

Process	Time taken (minute)
Hot compressed water (HCW)	15
Hot water extraction	30
Alkaline hydrogen peroxide	30
Neutralization	30
Mixing	30
Autoclave	20
Simultaneous saccharification and fermentation	4,320
Autoclave_2	20
Purification	1,440

In overlapping mode, the maximum occupancy time of all equipment units defines the process cycle time. According to Table 3, the maximum occupancy time is 72 hours with the SSF process. Therefore, the batch time is 101.667 hours and the cycle time is 72 hours.

With a bioethanol capacity of 13,950 liters per day, the time between production cycles is 24 hours. However, ethanol production requires 72.5 hours for the SSF process only. Therefore, it is necessary to compare and identify a suitable SSF tank for producing ethanol every 24 hours. For this comparison, there are 1, 2, 3, and 4 SSF tanks. Based on the production capacity under the same number of batches, there would be 12 batches for time comparison between ethanol batch production.

The graph in Figure 1 reveals that the SSF 1 tank takes the longest time between batches at 72.5 hours while the SSF 3 and SSF 4 tanks take the shortest time between batches of 24.5 hours. Hence, the SSF 3 tanks are used since these take the least amount of time to produce ethanol.

Regarding equipment utilization during three batches of ethanol production, the machines did not operate around 95% of the operation time. Hence, the production process should operate continuously with shorter equipment idling intervals. Figure 2 illustrates 23 cycles of the hot compressed water process, hot water extraction process, alkaline hydrogen peroxide process, neutralization process, mixing process, and autoclave process to produce sufficient substances for the further process of each batch and to increase the equipment performance.

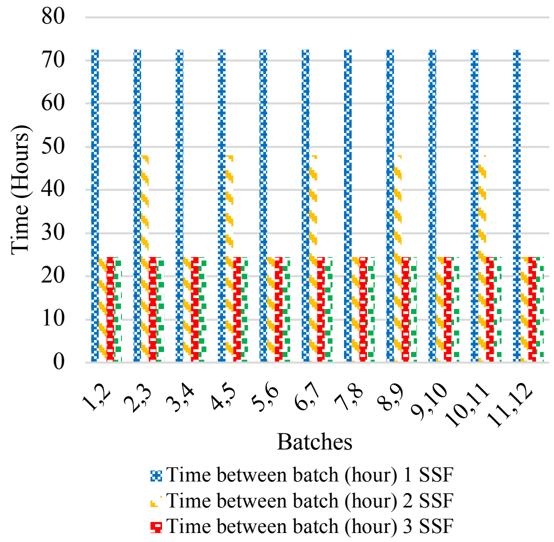

Fig. 1. Comparison of operating times for various SSF tanks

Therefore, the process can run continuously without waiting for each executed batch. After increasing the cycle with devices from the Aspen Batch Process Developer the equipment idle time was reduced to 26.361%. The equipment sizes used in each process are summarized in Table 4. As can be observed, the equipment sizes have decreased after batch scheduling, which not only reduces the cost involved but also increases its overall efficiency by 73.90%

Table 4. Equipment size in each process

Process	Equipment size before scheduling the batch process (kg of material)	Equipment size after scheduling the batch process (kg of material)
Hot compressed water (HCW)	451,248.53	18,802.022
Hot water extraction	227,830.15	9,492.9231
Alkaline H_2O_2	335,345.58	13,972.732
Neutralization	570,918.22	23,788.259
Mixing	325,069.22	13,544.551
Autoclave	325,069.22	13,544.551
Tank before SSF	325,069.22	13,544.551
SSF	238,360.81	9,931.7005
Autoclave	349,178.62	349,178.62
Tank after SSF	349,178.62	349,178.62
Purification	351,529.34	351,529.34
Storage	13,950 liters	13,950 liters

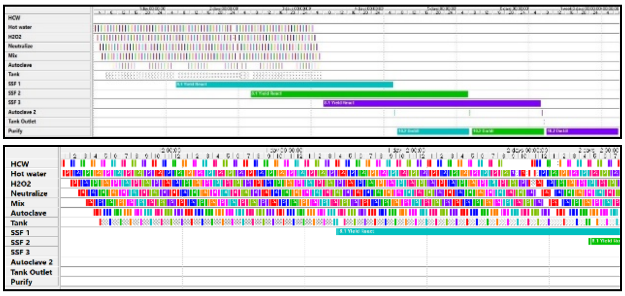

Fig. 2. Gantt chart showing the bioethanol production process from oil palm empty fruit bunches with the SSF 3 tank after adding more cycles to the pretreatment process

3.2. Minimizing Energy Consumption

The characteristics of 16 actual streams are listed in Table 5. The total heat loads for the cold and hot streams are 3.4x10^7 kJ/hr. and 6.07x10^7 kJ/hr, respectively.

The thermal integration in the Aspen Energy Analyzer is designed to improve the performance of HEN by focusing on the network operation [19]. HEN's features are designed to understand the current operation of the factory and help to narrow the gap between current operations and the proposed thermodynamics to improve efficiency.

Table 1. Data from the bioethanol production process for pinch analysis

Stream No.	Name	Type	T_{in} (°C)	T_{out} (°C)	Enthalpy (kJ/hr.)
1	PERMEATE_To_INPUMP12	Hot	80.00	79.50	2.00E+05
2	HOTWA.S4_To_HOTWA.S6	Cold	25.00	80.00	3.54E+06
3	S82_To_INMEMBRA	Cold	53.63	80.00	1.12E+05
4	AUTOCLAV.S23_To_AUTOCLAV.S1	Cold	25.06	121.00	3.27E+07
5	HCW.S22_To_HCW.S2	Cold	25.00	200.00	1.10E+07
6	TANKSTOR.S39_To_TANKSTOR.S1	Hot	121.00	40.00	1.53E+07
7	B34.S34_To_B34.S39	Cold	40.17	121.00	1.52E+07
8	ALKALINE.S1_To_ALKALINE.S3	Cold	25.00	70.00	3.67E+06
9	To Reboiler@COLUMN_TO_S31	Cold	80.33	80.84	1.69E+07
10	To Condenser@COLUMN_TO_S35	Hot	63.05	53.45	9.59E+06
11	SSF.FERMENT heat	Hot	40.00	39.50	1.14E+05
12	SSF2.B2_heat	Hot	40.00	39.50	1.04E+07
13	SSF3.B2_heat	Hot	40.00	39.50	1.04E+07
14	SSF3.FERMENT_heat	Hot	40.00	39.50	1.14E+05
15	SSF2.FERMENT_heat	Hot	40.00	39.50	1.14E+05
16	SSF.B2 heat	Hot	40.00	39.50	1.04E+07

Specific information is provided on the utility streams in the heat exchanger network to cool or heat the process streams. Cooling utility is available at 20 °C, while hot utility as low-pressure steam (LP) is available at 125 °C, medium-pressure steam (MP) at 175 °C, and high-pressure steam (HP) at 250 °C. The cost indices of cooling water, LP, MP, and HP are 2.12E-07, 1.9E-06, 2.2E-06, 2.5E-06, respectively.

The parameters for calculating the capital cost index value of the heat exchangers are as follows: a = 10,000, b = 800, c = 0.8. This research assumes that the rate of return is 10%, plant life 20 years, and hours of operation 7,200 hours/year. The minimum cooling load is 3.40E+7 (kJ/h). The capital cost is calculated as shown in Equation (1) [20]:

$$CC = a + b \times \left(\frac{Area}{N_{shell}}\right)^{c} \times N_{shell} \tag{1}$$

The operating cost is dependent on the calculated energy targets in the HEN, as shown in Equation (2) [20]:

$$OC = \sum\left(C_{hu} \times Q_{hu,min}\right) + \sum\left(C_{cu} \times Q_{cu,min}\right) \tag{2}$$

The TAC calculations for both the capital and operating costs associated with the heat exchangers in the HEN are shown in Equation (3) [20]:

$$TAC = A \times \sum CC + OC \tag{3}$$

The annualization factor is calculated as shown in Equation (4) [20]:

$$AF = \frac{\left(\frac{ROR}{100}\right) * \left(1+\frac{ROR}{100}\right)^{PL}}{\left(1+\frac{ROR}{100}\right)^{PL} - 1} \tag{4}$$

The graph in Figure 3 shows a cost index comparison of the process using a heat exchanger network between designs 1 to 10. It can be concluded that design 7 exhibits the lowest total cost of around 886,252.5 $/year. Details of the recommended designs are calculated by Equations (1) to (4).

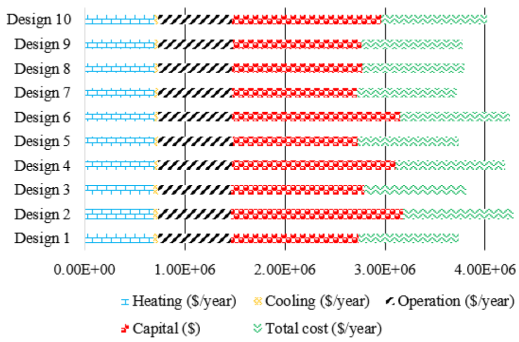

Fig. 3. Cost index comparison of the heat process using a heat exchanger network between designs 1 to 10

Therefore, heat exchanger network design 7 is used for minimizing energy consumption of the ethanol production process from oil palm empty fruit bunch. The network is manipulated though the grid diagram or the worksheet, as shown in Figure 4. It indicates hot steam and cold steam pairing.

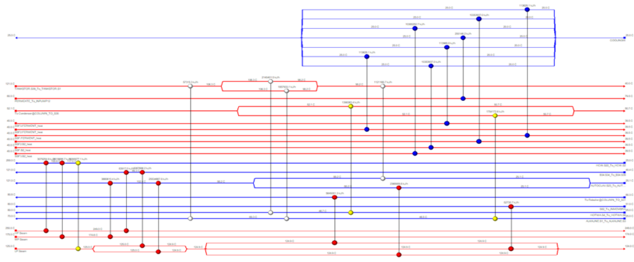

Fig. 4. Heat energy network design of minimum energy consumption

In Table 6, HEN is paired with the utility stream (COOLINGW, LP STEAM, MP STEAM, and HP STEAM). It is not necessary to add heating equipment during the production process for loading the utility steam because the utility stream can load itself. For internal exchange, it is necessary to add HeatX equipment during the production process for heat exchange between the hot and cold stream.

Table 6. Specifications of heat exchanger networks

Hot stream	Cold stream	Area (m²)	N_{shell}
PERMEATE_To_INPUMP12	COOLINGW	5.12E+00	1
SSF2.B2_heat	COOLINGW	8.84E+02	2
To Condenser@COLUMN_TO_S35	ALKALINE.S1_To_ALKALINE.S3	3.07E+01	1
LP Steam	S82_To_INMEMBRA	2.07E-01	1
LP Steam	B34.S34_To_B34.S39	1.47E+01	1
SSF.FERMENT_heat	COOLINGW	9.71E+00	1
TANKSTOR.S39_To_TANKSTOR.S1	ALKALINE.S1_To_ALKALINE.S3	4.13E+01	1
MP Steam	HCW.S22_To_HCW.S2	1.64E+01	1
LP Steam	To Reboiler@COLUMN_TO_S31	6.93E+00	1
To Condenser@COLUMN_TO_S35	HOTWA.S4_To_HOTWA.S6	2.57E+01	1
LP Steam	AUTOCLAV.S23_To_AUTOCLAV.S1	8.18E+01	1
HP Steam	HCW.S22_To_HCW.S2	9.14E+00	1
LP Steam	HCW.S22_To_HCW.S2	4.15E+01	1
MP Steam	AUTOCLAV.S23_To_AUTOCLAV.S1	3.98E+01	1

SSF2.FERMENT_heat	COOLINGW	9.71E+00	1
TANKSTOR.S39_To_TANKSTOR.S1	AUTOCLAV.S23_To_AUTOCLAV.S1	1.02E+01	5
TANKSTOR.S39_To_TANKSTOR.S1	HOTWA.S4_To_HOTWA.S6	1.09E+01	1
HP Steam	B34.S34_To_B34.S39	5.15E+01	1
LP Steam	AUTOCLAV.S23_To_AUTOCLAV.S1	5.33E+00	1
SSF3.B2_heat	COOLINGW	8.87E+02	2
SSF.B2_heat	COOLINGW	8.84E+02	2
SSF3.FERMENT_heat	COOLINGW	9.73E+00	1
TANKSTOR.S39_To_TANKSTOR.S1	ALKALINE.S1_To_ALKALINE.S3	7.64E+00	1

The new information is then adjusted using the heat exchanger network in Aspen Plus, as shown in Figure 5.

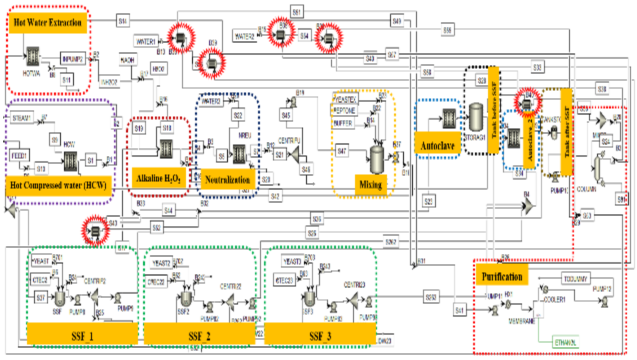

Fig. 5. Final design of the bioethanol production process using the heat exchanger network

Data on energy network design 7 are calculated by Equations (1) to (4). A comparison of the network cost indices between the bioethanol production process with and without the heat exchanger network is shown in Table 7. Each cost index value is derived from the calculation.

Table 7. Network cost index comparison of the bioethanol production process

	Cost Index	
	Bioethenol process using the heat exchanger network	**Bioethenol process using a base case**
Heating ($/year)	622,342.1	1,058,564.08
Cooling ($/year)	39,661.82	70,816.09
Operation ($/year)	662,003.9	1,129,380.17
Capital ($)	1,034,262	989,213.85
Total cost ($/year)	886,252.5	1,343,861.37

As can be observed from Table 7, the cost per year of bioethanol production process with and without the heat exchanger network are 886,252.5$/year and 1,343,861.37$/year, respectively. This means that using the heat exchanger network in the bioethanol production process can reduce costs by around 34.05% per year.

3.3. Sensitivity Analysis

The original feed flow rate is 1,967 kg/hr. When sensitivity analysis was applied to the feed flow rate it ranged from 0 kg/hr. to 30,000 kg/hr. The results indicate changes in the mass fraction (ethanol), utility cost (cooling water, LP, MP, HP), and carbon dioxide emissions from the utility (LP, MP, HP). The system response to changes in the feed flow rate is shown in Figure 6.

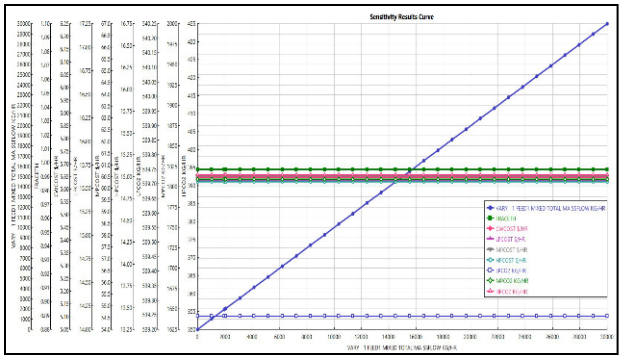

Fig. 6. Sensitivity analysis

From the sensitivity curve, it can be concluded that the mass flow rate does not affect the key parameters. These parameters include the mass fraction (ethanol), utility cost (cooling water, LP, MP, HP), and carbon dioxide emissions from the utility (LP, MP, HP). The whole process can be adjusted and redundancy maintained to allow for the fluctuating input rate of the raw material. Therefore, the advantage of this process is that it can be further designed using a suitable dynamic control technique.

3.4. Process Dynamics and Control

The control structure is fundamental to the time-based simulation. The controller can prevent failure occurring during actual ethanol production [21]. The control design for ethanol purification in this research involves the pervaporation process, consisting of a column (proposed to purify around 85% of ethanol [22]) and a membrane (recommended to refine around 99.5% of ethanol [23]). The pervaporation process features the azeotropic point between ethanol and water. The steady-state design was performed in Aspen Plus and then exported to a flow driven simulation in Aspen Plus Dynamics. The control structure was necessary for the column to maintain the ethanol specification. Column pressure was controlled by "Column_CondPC", while "Column_DrumLC" controlled the reflux drum level. The base level of the column was controlled by "Column_SumpLC" as shown in Figure 7. The setpoints of the column pressure, control reflux drum level, and control base level of the column were 0.3, 1.6002, 10.9728, respectively.

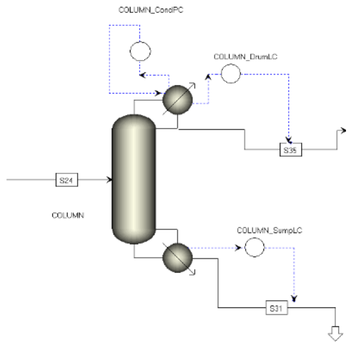

Fig. 7. Control structure of a column

The graphs in A, B, and C of Figure 8 show each controller running dynamically for five hours. It can be concluded that when running the control system for column pressure (Column_CondPC), reflux drum level (Column_DrumLC), and base level of the column (Column_SumpLC), it can stabilize the system in approximately 2, 3, and 2.5 hours, respectively.

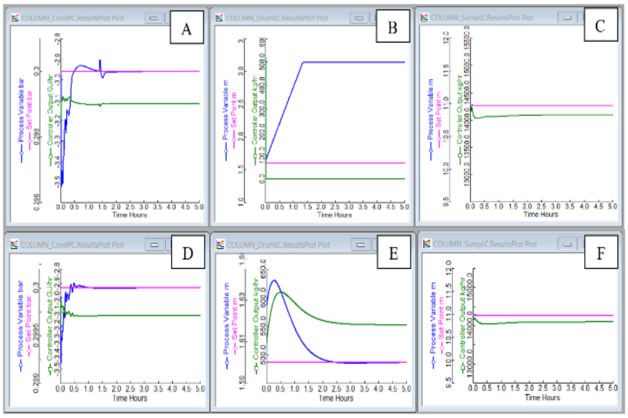

Fig. 8. Result plots

Since driving in the steady-state is time-consuming, the tuning parameters algorithm with the IMC tuning rule is proposed for gain, integral time, and action. This is suitable for a control system involving column pressure (Column_CondPC), reflux drum level, (Column_DrumLC), and column base level (Column_SumpLC). Aspen Plus Dynamics can calculate the optimal tuning parameters, as shown in Table 8.

Following adjustment of the parameters, the graphs in D, E, and F of Figure 8 show the configuration of each controller faceplate when running dynamically for five hours. It can be concluded that when running the control system for column pressure (Column_CondPC), reflux drum level (Column_DrumLC), and column base level (Column_SumpLC), it can stabilize the system in approximately 1 hour, 5 hours, and 1 hour, respectively.

Table 8. Controller tuning parameters

Controller Name	Column_ CondPC	Column_ DrumLC	Column_ SumpLC
Purpose	Control column pressure	Control reflux drum level	Control base level of column
Controller Type	PI	PI	PI
Gain (%)	2.285141	112.7013	18.50477
Integral time (min)	11.55855	2.776729	8.167503
Action	Reverse	Reverse	Direct

4. Conclusion

This research examines the bioethanol production process using oil palm empty fruit bunches as the substance. The purpose of this thesis is to minimize the operation time and reduce energy consumption through simulation of the bioethanol production process involving oil palm empty fruit bunches.

The initial aim of the research is to identify an optimal simulation process for producing 10,000 liters per day of bioethanol from oil palm empty fruit bunches while minimizing the operation time. The overlapping operational process was selected, according to the principles of batch scheduling. The advantage of the overlapping operation is that it takes less time to produce ethanol. Prior to improving the simulation process, it took 101.7 hours to produce 13,950 liters of bioethanol from oil palm empty fruit bunches representing a cycle time of 72 hours from the SSF process with continuous production. Since bioethanol production from oil palm empty fruit bunches uses the SSF process during the time cycle, it is necessary to identify the most suitable equipment size in the SSF process to minimize the time taken to obtain ethanol between batches. There are four tanks in the SSF process. The results of bioethanol production from oil palm empty fruit bunches reveal that SSF 1 tank can produce ethanol every 72.5 hours, while SSF 2 tanks can produce ethanol every 24.5 hours, alternating every 48 hours. Using the SSF 3 and SSF 4 tanks resulted in ethanol being produced every 24.5 hours. Therefore, the SSF 3 tanks are used because they are smaller than the others and can produce ethanol at the fastest rate by adding 24 cycles to each process prior to SSF. The results indicate that SSF 3 can increase equipment performance utilization to 79% as well as minimizing energy consumption. The results reveal that the total cost of the process using the heat exchanger network is 0.9 M$/year, while for the base case process the total cost is around 1 M$/year. Therefore, it can be concluded that the process with the heat exchanger network is more cost-effective than the process without (i.e. the base case). This represents a potential cost reduction of around 34.05% per year.

According to the sensitivity analysis, it can be concluded that the mass flow rate does not significantly affect the critical design of the parameters. This is because the process has been adjusted to suit the changing input rate of the raw material, which does not affect the output, and is an advantage of this process.

Finally, bioethanol production from oil palm empty fruit bunches is simulated in terms of process dynamics and control. The tuning parameters use the IMC tuning rule to calculate the gain, integral time, and action suitable for the control system, following adjustment of the parameters during configuration of each controller faceplate. Therefore, this system can enter a stable state more quickly than one which does not use parameters calculated by applying IMC rules. It can be concluded that when running dynamically for five hours, the column pressure (Column_CondPC), control reflux drum level (Column_DrumLC), and control base level of the column (Column_SumpLC) can stabilize the system in approximately 1 hour, 1.5 hours, and 1 hour, respectively.

Acknowledgments

This research is supported in part by the Graduate Program Scholarship from the Graduate School, Kasetsart University and Thailand Advanced Institute of Science and Technology–Tokyo Institute of Technology (TAIST-Tokyo Tech) program under the National Science and Technology Development Agency (NSTDA). Funding for this work has been provided jointly by the office of the National Research Council of Thailand (NRCT), in collaboration with the National Natural Science Foundation of China (NSFC) under the topic of Renewable Energy, and Kasetsart University.

References

[1] S. Mohapatra, R. C. Ray, and S. Ramachandran, “Bioethanol from Biorenewable Feedstocks: Technology, Economics, and Challenges”. Bioethanol Production from Food Crops, pp. 3–27, 2019.

[2] Y. Sudiyani, D. Styarini , E. Triwahyuni, K. C. Sembiring, Y. Aristiawan, G. Abimanyu and M. H. Han, “Utilization of biomass waste empty fruit bunch fiber of palm oil for bioethanol production using the pilot-scale unit”. Energy Procedia, vol. 32, pp. 31–38, 2013.

[3] G. Papa, S. Rodriguez, A. George, A. Schievano, V. Orzi, K. Sale, S. Sungh, F. Adani, and B. Simmons, “Comparison of different pretreatments for the production of bioethanol and biomethane from corn stover and switchgrass”. Bioresource Technology, vol.183, pp. 101–110, 2015.

[4] C. C. Cormos, A. Imre-Lucaci, A. M. Cormos, Z. Tasnadi-Asztalos, and M. D. Lazar, “Computer-Aided Chemical Engineering”. Elsevier. New York, pp.6, 2013.

[5] S. Bharadwaja, S. Singh, and V. S. Moholkar, “Design and optimization of a sono-hybrid process for bioethanol production from Parthenium hysterophorus”. Journal of the Taiwan Institute of Chemical Engineers, vol.51, pp. 71–78, 2015.

[6] M. Martín, and I. E. Grossmann, “Design of an optimal process for enhanced production of bioethanol and biodiesel from algae oil via glycerol fermentation”. Applied Energy, vol.135, pp. 108–114, 2014.

[7] V. Gonela, and J. Zhang, “Design of the optimal industrial symbiosis system to improve bioethanol production”. Journal of Cleaner Production, vol.64, pp. 513–534, 2014.

[8] A. Romaní, H. A. Ruiz, F. B. Pereira, J. A. Teixeira, and L. Domingues, “Integrated approach for effective bioethanol production using whole slurry from autohydrolyzed Eucalyptus globulus wood at high-solid loadings”. Fuel, vol. 135, pp. 482–491. 2014.

[9] P. Fasahati, H. C. Woo, and J. J. J. A. E. Liu, “Industrial-scale bioethanol production from brown algae: Effects of pretreatment processes on plant economics”. Applied Energy, vol. 139, pp. 175–187, 2015.

[10] E. Betiku and Taiwo, “Modeling and optimization of bioethanol production from breadfruit starch hydrolyzate vis-à-vis response surface methodology and artificial neural network”. Renewable Energy, vol.74, pp. 87–94, 2015.

[11] N. A. A. Adnan, S. N. Suhaimi, S. Abd-Aziz, M. A. Hassan, and L. Y. Phang, “Optimization of bioethanol production from glycerol by Escherichia coli SS1”. Renewable Energy, vol. 66, pp. 625–633, 2014.

[12] S. K. Wahono, V. T Rosyida, C. Darsih, D. Pratiwi, and A. Frediansyah, “Optimization of simultaneous saccharification and fermentation incubation time using cellulase enzyme for sugarcane bagasse on the second-generation bioethanol production technology”. Energy Procedia, vol. 65, pp. 331–336, 2015.

[13] N. Trivedi, C. Reddy, R. Radulovich, and B. Jha, “Solid-state fermentation (SSF)-derived cellulase for saccharification of the green seaweed Ulva for bioethanol production”. Algal Research, vol. 9, pp. 48–54, 2015.

[14] C. Ofori-Boateng, and K. T. Lee, “Ultrasonic-assisted simultaneous saccharification and fermentation of pretreated oil palm fronds for sustainable bioethanol production”. *Fuel*, vol. 119, pp. 285–291, 2014.

[15] F. Mazzetto, G. Simoes-Lucas, R. A. Ortiz-Gutiérrez, D. Manca, and F. Bezzo, “Impact on the optimal design of bioethanol supply chains by a new European

Commission proposal". Chemical Engineering Research and Design, vol. 93, pp. 457–463, 2015.

[16] G. Corsano, Y. Fumero, and J. M. Montagna, "Integrated decision making for the optimal bioethanol supply chain". Energy Conversion and Management, vol. 88, pp. 1127–1142, 2014.

[17] T. X. Do, Y. i. Lim, S. Jang, and H. J. Chung,."A hierarchical economic potential approach for techno-economic evaluation of bioethanol production from palm empty fruit bunches". Bioresource technology, vol.189, pp. 224–235, 2015.

[18] L. Burtseva, R. Romero, S. Ramirez, V. Yaurima, F. F. González-Navarro, and P. F. Perez., Lot processing in hybrid flow shop scheduling problem. InTech, 2012.

[19] I. Bulatov, "Software tools for heat integration." Handbook of Process Integration (PI). Woodhead Publishing, pp.1059–1085, 2013.

[20] V. G. Bokan, and M. U. Pople, "Design of Heat Exchanger Network for VCM Distillation Unit Using Pinch Technology." International Journal of Engineering Research and Applications, Vol.5(6), pp.80–86, 2015.

[21] E. Zio, F. Di Maio, and M. Stasi, "A data-driven approach for predicting failure scenarios in nuclear systems." Annals of Nuclear Energy, vol. 37(4), pp. 482–491, 2010.

[22] A. Verhoef, J. Degreve, B. Huybrechs, H. van Veen, P. Pex, and B. Van der Bruggen, "Simulation of a hybridpervaporation–distillation process." Computers & Chemical Engineering, vol. 32(6), pp.1135–1146, 2008.

[23] B. Suleiman, A. S. Olawale, and S. M. Waziri, "Exergetic and economic assessment of distillation hybrid configurations for bioethanol refining." International Journal of Thermodynamics, vol.17(4), pp. 221–231, 2014.