Net Energy Analysis of Molasses Based Bioethanol Production in Indonesia

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Abstract: Molasses is mostly used as feedstock for the bioethanol production in Indonesia. Bioethanol industries has the potential to be more developed if the mandate of blending gasoline with 5% bioethanol is implemented. However, some previous studies abroad have shown that mostly the net energy for producing bioethanol is negative. The main purpose of this research is to analyze the net energy requirement if a bioethanol conversion plant from scenario of a bioethanol producer in East Java. Bioethanol conversion processes inside the plant are pre-fermentation, fermentation, evaporation, distillation and dehydration. Method which was used in this research are modelling and calculation made on monthly basis for plant capacity of 30,000 KL/ year ethanol of 99.5% purity. The result shows that the total energy required to produce 1 L of ethanol is 4.55 MJ. The energy content of 1 L ethanol is 23.46 MJ. The largest energy requirement is for evaporation process (62%) followed by distillation process (33%). Thus, the net energy requirement for bioethanol production process is positive.

Keywords: Molasses, bioethanol, net energy, evaporation, distillation

1. Introduction

Petroleum dominates the total primary energy supply in the world and the global demand of energy keeps increasing. It is predicted that the energy consumption for transportation increases with an annual average rate of 1.4% and will reach 155 quadrillion British thermal units (Btu) in 2040, from 104 quadrillion Btu in 2012 (U.S. Energy Information Administration, 2016). Unfortunately, fossil fuels are non-renewable natural resources and are depleted. This has led to the importance of the substitution of fossil fuels from renewable sources. One of the promising replacements is bioethanol. Various feedstocks such as corn, sugar cane, molasses, bagasse, sorghum, and others are used in the production of bioethanol (Ibeto, Ofoefule, & Agbo, 2011). In Indonesia, the production of biofuels is expected to increase due to the Ministry of Energy and Mineral Resources Regulation No. 12 Year 2015 which mandates the 5% bioethanol blending by 2020. It is expected that in 2017 and 2018, Indonesia will produce 205 million liters of bioethanol (Wright & Rahmanulloh, 2015).

There are concerns about the energy required in the bioethanol production processes due to the previous studies done by other researchers. Study done by Khatiwada and Silveira (2009) reveals that the production of molasses-based ethanol in Nepal has negative energy value of 13.05 MJ/L ethanol. The largest proportion of the energy inputs are used for corn feedstock and for the electricity and steam used in the fermentation/ distillation process (Pimentel & Patzek, 2008). The energy which is consumed during the distillation process has caused some concerns due to the low thermodynamic efficiency of columns (Patil, Patil, & Bhole, 2016).

Miller and Spoolman (2004) expound net energy as the amount of high quality energy available from an energy source minus the amount of energy needed to make it available. Net energy analysis helps to enhance all views and decisions in the energy field because energy forecasting and policy issues are based on the measurement of energy flows related with energy supply and conservation technology (Leach, 1975).

A study at a sugar mill in Lumajang, East Java (PG Djatiroto) which was done by shows that in the fermentation process, urea production consumed energy of 0.01 MJ/L ethanol and the electricity consumption is 0.21 MJ/L (Venkata, 2013). Electricity is mostly consumed in distillation process.

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Energy analysis of the molasses-based bioethanol production is important to find out whether the production of bioethanol from molasses is energy efficient or not (Gallegos, Suministrado, Elauria, & Elauria, 2014). Furthermore, currently there are no studies available on the net energy analysis of the production of bioethanol from molasses in Indonesia. Hence, it is necessary to conduct research on the analysis of the net energy of molasses-based bioethanol production in Indonesia.

2. Research Method

The research framework is divided into three sections which are data collection, modelling and calculation. Data were collected from a molasses-based bioethanol plant located in Mojokerto, East Java. Data taken during the visit were about production capacity, whole processes for the conversion of bioethanol, equipment and sizes and also input-output in the whole processes. After collecting data, the next step was to develop model based on the bioethanol plant. Process flow diagram of bioethanol plant was developed, missing or unavailable data were completed by looking from references. The last step was to calculate the total energy requirements. Before calculating the total energy requirements, there were some data which need to be completed by means of calculation.

Energy input is categorized into three which are steam (heat), mechanical, and pump. Cooling water was considered as an energy output and there was also energy loss in the form of heat loss.

Formula used for calculating energy required for heating, cooling and heat loss is

$$Q = m \, c \, \Delta T \tag{1}$$
$$Q = m \, c \, \Delta T + m \, \lambda \tag{2}$$

where mass flow rate, specific heat capacity and temperature differences were used in the calculation. Latent heat was used in calculation when phase transition occurred. Some temperatures which were unknown were assumed based on other literature and also specifications of the equipments.

Energy required for pumping is calculated with

$$P_h = \frac{q \, \rho \, g \, h}{3.6 \, x 10^6} \tag{3}$$
$$P_s = \frac{P_h}{\eta} \tag{4}$$
$$P = P_h + P_s \tag{5}$$

Flow rate, density, gravity, and differential head were used for the calculation. In this calculation, differential head was assumed.

Energy required for the use of impeller in fermentation process is calculated with

$$P = \frac{N_p \, x \, N^3 \, x \, D_a^5 \, x \, \rho}{g_c} \tag{6}$$

in this calculation, assumption was made for power number. Power number, agitator speed, impeller diameter, and density were used for calculating the power consumed by the impeller.

3. Results and Discussions

Primary data were taken at a molasses-based bioethanol plant in Mojokerto, East Java with capacity production of 30,000 KL/ year of 99.5% purity of ethanol. The bioethanol conversion plant is integrated with a Sugar Mill. Electricity used in the bioethanol plant is from the grid (PLN) and steam is generated in the sugar mill. Processes happening inside the plant are pre-fermentation, fermentation, evaporation, distillation, and dehydration. Modelled process flow diagram of the bioethanol production plant can be seen in figures below.
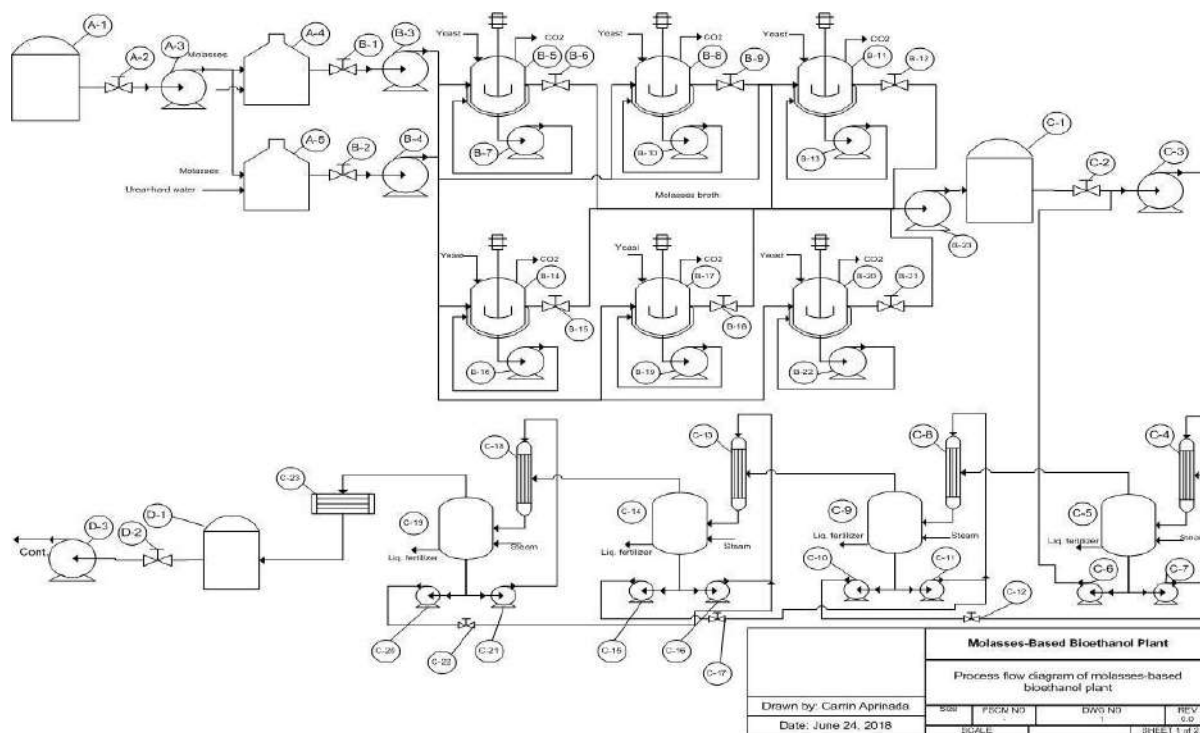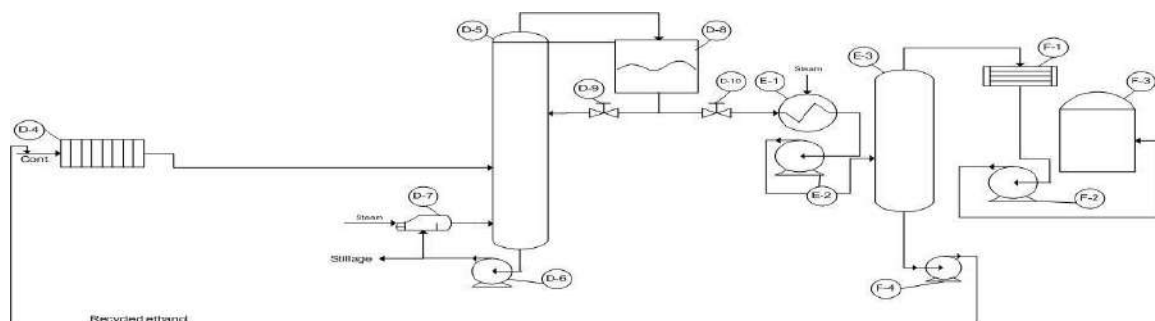
Figure 1. Modelled Process Flow Diagram 1

Figure 2. Modelled Process Flow Diagram 2

The total energy requirement per month for the whole process is shown in the table below.

Table 1: Net Energy Requirement for whole Processes

Section	Total Energy Input (MJ/ month)	Total Energy Output (MJ/ month)	Total Energy Losses (MJ/ month)	Energy Input Allocation (%)
Propagation	524,838.50	-	-	3%
Fermentation	219,978.79	-	499,758.97	1%
Evaporation	9,321,856.48	662,236.42	-	62%
Distillation	4,966,727.24	1,205,976.00	-	33%
Dehydration	95,109.16	2,285,223.30	-	1%
Total	15,128,510.17	4,153,435.72	499,758.97	100%
Net Requirement	11,474,833.42			
ΔHc	59,130,000.00			

During propagation, total energy input is 524,838.50 MJ/month which mostly came from heating since during this process mixture was heated to be prepared before entering fermenters. There is also a small portion of energy input which came from the utilization of pump.

In fermentation, the total energy input is 219,978.79 MJ/month which were from the use of steam (heat), impellers, and pumps. The energy input in this process is dominated by the utilization of heat. There is also energy loss which amounts to 499,758.97 MJ/month which was from the loss of heat happening when the mixture is being transferred from propagation tank into fermenters.

The total energy input for evaporation process is 9,321,856.48 MJ/month which is relatively high. Most of the energy input is in the form of heat which was used for the operation of heat exchangers. There is also condensate as an energy output amounting to -662,236.42 MJ/month which is assumed to be reuse as heating fluid for heat exchangers.

In distillation process, the total energy input is 4,966,727.24 MJ/month which mainly came from the use of steam (heat) in the distillation column. There is also an energy output of -1,205,976.00MJ/month from the utilization of cooling water to cool down distillate. Cooling water is then recovered to be reused in the cooling tower.

In the last process, dehydration, the total energy input is 95,109.16 MJ/month with the largest coming from pumps which is around 91,316.16 MJ/month. Energy requirement for pumps is relatively high in this process because the output flowrate is quite high. There is also total energy output of -2,285,223.30 MJ/month which comes from the utilization of condenser. In this process, the condensate is assumed to be recovered and utilized as hot water for fermenters and the remaining is used for cleaning equipment.

Net energy requirement to produce 2,520,000 L of ethanol is 11,474,833.42 MJ while the energy content of the produced ethanol is 59,130,000 MJ. Therefore, the total energy required to produce 1L of ethanol is positive 4.55 MJ with an energy ratio of 19.41%. From Table 1 above, the total energy input for whole processes is 11,474,833.42 MJ/month. There is also energy output with the total of 4,153,435.72 MJ/month and energy losses of 499,748.97 MJ/month. Process with highest energy requirement is evaporation amounting to 9,321,856.48 MJ/month (62% from the total energy inputs). The second highly energy-intensive process is distillation (33%) with total energy input which amounts to 4,966,727.24 MJ/month.

Table 2: Total Energy Inputs, Outputs and Losses

	Energy Input (MJ/month)	Energy Output (MJ/ month)	Energy Losses (MJ/ month)	Distribution of Energy Inputs (%)
Steam	14,926,098.29	-	-	99%
Mechanical	56,945.37	-	-	0%
Pump (s)	145,466.51	-	-	1%
Cooling water	-	4,153,435.72	-	-
Heat dissipation	-	-	499,758.97	-

The energy input is dominated by the utilization of steam (99%). Remaining inputs are from pumps for around 1% followed by mechanical (impeller) for 0%. Despite the amounts of pumps used in

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the bioethanol plant which is around 24 pumps, pumps only contribute for very small percentage to the whole energy inputs.

Study done by Cheroennet and Suwanmanee (2017) in Thailand for corn ethanol production shows energy input needed to produce 1L of ethanol is 15.24 MJ. This result is higher than the result from this study because the scope of the study done in Thailand is started from corn plantation until the utilization of the ethanol while the boundary of this study is only bioethanol conversion processes.

Other study done by Nguyen et al. (2008) in Thailand reports that the net energy required is 26.85 MJ/L ethanol which is also higher than this study. As a matter of fact, the study in Thailand includes sugar cane farming, sugar milling, transportation and ethanol conversion phase which led to higher energy requirement. Meanwhile, the scope of this study is focusing only on the conversion processes of bioethanol since molasses which is used as feedstock is a by-product of a sugar mills.

Another study done by Khatiwada and Silveira (2009) for the production of molasses ethanol in Nepal reveals that the total net energy requirement is 34.26 MJ/L ethanol which is much higher than the result from this study. The result from Nepal is higher because the scope of the study includes sugar cane farming (chemicals, irrigation, human labor), transportation, sugar cane milling and bioethanol conversion. The largest energy requirement in Nepal case study is for distillation process. The result is different from this study because the production capacity in Nepal is much higher (30 m^3/ day), there is also a rectification in the distillation process while the distillation process in this study does not have rectification. In addition, bioethanol conversion phase in Nepal consists of fermentation, distillation and dehydration without having evaporation process.

4. Conclusion

To conclude, the net energy requirement for the whole process of bioethanol conversion in a molasses-based bioethanol industry with capacity of 2,520,000 L/month is relatively small (19.41%) compared to the energy content of the bioethanol itself. Total energy required to produce 1 L of ethanol is 4.55 MJ. Thus, the net energy requirement for bioethanol conversion processes is positive. Additionally, the most energy-intensive process is evaporation dominating with 62% of the total energy inputs. Followed by distillation as the second highest energy-intensive process amounting to 33% of the total energy required.

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