Process integration potential between biodiesel production from palm oil and 2nd generation bioethanol production from empty fruit bunches (EFBs) in Brazilian context: Thermo-economic and environmental evaluation

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1 - Introduction

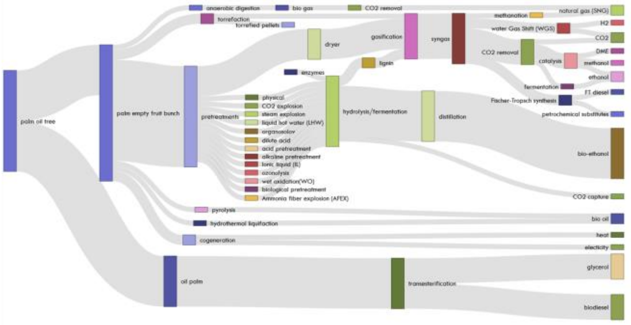
Palm oil is an edible vegetable oil which is extracted from palm oil tree. It is used in varieties of industries from food to pharmaceutical products. It is one of the most demanded and consumed vegetable oil in the world. In 2012, 5.6 million tons of it were converted to biofuels.

Brazil's Amazon region has one of the largest areas for cultivation of palm oil (mostly in deforested lands). It was the 10th biggest producer of palm oil in 2011. The production has increased by 200% in the period of 2004 to 2011. This leads to the increase in the amount of residues from the industry. In order to be sustainable, these (mainly empty fruit bunch) can be utilized in a biorefinery concept to produce varieties of high value-added products. [1]

2 – Materials and methods

It was observed that among the residues of biodiesel production from crude palm oil, empty fruit bunches, palm press fibres, and palm kernels have the potential of being used for bioethanol production. Several pathways have been studied and described, including thermo-chemical and bio-chemical ones (Figure 1). The focus is on biochemical pathways in which lignocellulosic biomass should be first pretreated to break the binds among cellulose, hemicellulose and lignin. Later, it will be hydrolysed into sugar which can be further fermented into ethanol.

Figure 1. Possible pathways from palm tree to biofuels



Biochemical pathway using dilute acid pretreatment has been modelled using Aspen Plus®. The empty fruit bunch is selected as the raw material with 60% moisture content. It is composed of 33.5% glucose, 26.8% Xylan, 20.1% lignin, and 8.4% extractives with traces of Arabinan, Galactan, and ash [2]. The pretreatment part has been modelled using data from [2]. The acid concentration is 1.025% (v/v) at 160 ºC. Hydrolysis data comes from [3]. The outlet of hydrolysis has glucose concentration of about 5.7% (w/w). Using a 3-effect evaporator this concentration has increased to 6%, 11% and 17%, respectively before fermentation. The solid loading is 10% w/v with 1.5 days residence time at 50 ºC. The fermentation is modelled based on a typical sugar fermentation [4]. The mixture produced in fermentation (with the alcohol content of around 7-10%) is sent to distillation unit in which hydrous ethanol will be produced with purity of 93.8%. As mentioned in [4], Brazilian distilleries use a 5 column ethanol distillation, namely A (wine stripping column), A1 (wine rectification column), D (concentration of second grade alcohol), B (rectification column), and B1 (stripping column). The combination of A, A1, and D columns is the distillation column. Hydrous ethanol is obtained from column B1. The columns are modelled using RadFrac unit in Aspen Plus®. Detailed description of simulation parameters can be found in [4], [5].

The model of biodiesel production from crude palm oil is based on data from [6]. The composition of crude palm oil is give in the supplementary document of [7]. Trans-esterification with an alkali catalyst (NaOH) is the main step to convert oil to biodiesel, however it requires very small amount of FFA to be present in the oil as it can reacts with the catalysts to produce soap and water. Since CPO has around 6% FFA [7], it requires a pretreatment step to convert FFA into biodiesel. An esterification reaction with acid catalyst (H_2SO_4) is modelled for this reason.

Table 1 provides the sizing parameters of the plants.

Table 1. Parameters related to the size of the plants

Parameter	Value	Unit	Ref.
plantation area	20,000	ha/plant	[8]
operating time	3,680	hr/yr	
Size of biodiesel plant	30.5	t CPO/hr	
Size of bioethanol plant	25	t EFB/hr	

CPO = crude palm oil

3 – Results and discussions

Total cost of the bioethanol plant and its minimum energy requirement are provided in Table 2 and Table 3, respectively. Considering 30 years of plant lifetime and an internal rate of return 4%, cost of EFB 60 USD/t, and cost of enzyme 1.32 USD/kg [9], the production cost of bioethanol is estimated around 1.44 USD/kg. Increasing the operating time to 8670 hrs/yr will reduce the cost to 1.15 USD/kg.

Table 2. Summary of capital cost of bioethanol plant

Bioethanol plant	unit	value
Total capital cost	USD	15,590,438
Equipment cost	USD	1,962,000
Total installed cost	USD	5,832,400

Table 3. Minimum energy consumption of bioethanol plant

Name	Rate	Rate units	Cost
Electricity	186	kW	6.51
Cold water	190,350,700	kJ/hr	256.97
HP steam	60,964,360	kJ/hr	688.90
LP steam	12,201,790	kJ/hr	99.81
MP steam	63,583,020	kJ/hr	588.78

As shown in Figure 2, the major part of heating requirement in bioethanol plant is the air preheating for drying biomass and evaporation of water in the concentration columns. As it can be seen there is a huge amount of heat available at high temperature which can be used in biodiesel plant, (biodiesel plant heat requirement is mainly below 100 ºC (Figure 3), hence the heat integration of the two plants can significantly reduce the utility consumptions and thus reduce the production cost of the two plants.

Figure 2. Utility integrated grand composite curve of bioethanol plant.

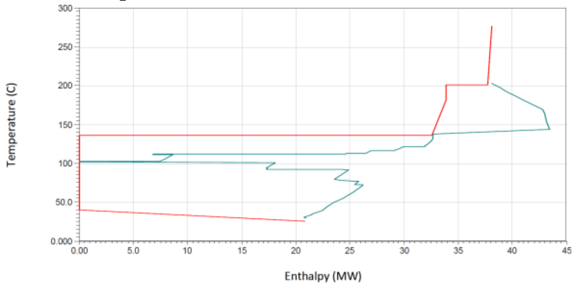


Figure 3. Utility integrated grand composite curve of biodiesel plant.

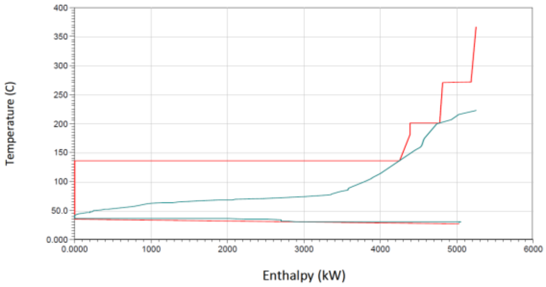


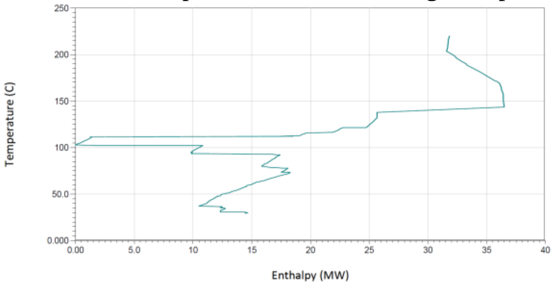
Figure **4** shows the grand composite curve of the integrated biodiesel and bioethanol plant with data presented in Table 4. The potential of 26.5% and 44.8% reductions in heating and cooling utilities, respectively, can be observed in the integrated plants when compared to the two stand-alone plants.

Table 4. Minimum energy requirement of the integrated plant.

Utility	unit	Total[1]	Integrated	change[2]
Heating	kJ/hr	156,187,490	114,856,764	-26.5
Cooling	kJ/hr	94,249,964	51,988,163	-44.8

1 sum of two plants, no integration
2 percentage of change in energy consumption

Figure 4. Grand composite curve of the integrated plant.



4 – Conclusion

A thermo-economic analysis of biodiesel and bioethanol production from palm oil in Brazilian context has been carried out. The analysis demonstrates the great potential of energy and resource savings in an integrated biodiesel and bioethanol plant.

5 – Acknowledgement

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6 - Bibliography

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