Techno Economic Analysis Study of Dry Leaves Via Low Temperature Mechanism

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Abstract— **Energy has played a crucial part in our daily life no matter what or where we live in this world. The common source of energy is fossil fuels. This fossil fuels are digged and sourced from undersea and brought to the surface. However, this source is unreliable as it causes pollution, unrenewable, and depleting over the years. That is why, a better and more reliable source of energy which is biomass is proposed in this paper. That is because biomass can be obtained from anywhere and anytime. It provides the same amount of energy and have the same purpose of fuels if treated and processed correctly. Biomass used as a fuel is renewable and always available. The carbon dioxide that are released by the biomass fuel is taken back by plants. This way, the fuel would not cause any pollution to the environment and at the same time it produced oxygen. There are several ways of converting biomass into source of energy which in this study, the torrefaction and pyrolysis process will be used as a guideline process. Both processes have the same purpose which is converting the biomass into 3 products which are biochar, biofuels and syngas. However, the equipment and yield will differ accordingly. The biomass that will be use as raw materials is dry leaves. The ultimate analysis of the dry leaves will be obtained first and around 10,000 kg of dry leaves are used as a basis at the starting process. A simulation will be created to compare the two process in terms of yield and cost. The tools used for this study is Aspen Hysys. For pyrolysis, a yield of coal, fuel, and gas obtained are 23.4%, 48.8% and 27.8% respectively while torrefaction obtained a yield of 70.36%, 11.51% and 18.13% respectively.**

Keywords: *Biomass, Dry Leaves, Pyrolysis, Torrefaction, Hysys*

I. INTRODUCTION

Biomass is considered to be an advancement derived from fossil fuels. Biomass is a biological material that can be obtained from living plant matter or crops that can be processed into fuel and heat. Biomass is a carbon neutral fuel and it takes carbon out of the atmosphere and return the amount back as it is burned. In terms of sustainability, biomass can be considered as sustainable even in the future due to its ability to replenish with new growth after it is harvested. This will not only save cost, but also maintains the carbon cycle without increasing the carbon dioxide quantity in the atmosphere that may cause global warming and climate change especially in countries like Malaysia. [5]

Biomass waste contain energy that can be reused to benefits the daily life and at the same time, this process can also help to dispose the unwanted waste. In Malaysia, as stated by Kementerian Tenaga, it shows that an estimation of 33,000 tonnes of waste were produced a day in 2016. This shows that there was a huge amount of energy source that can be recycled in Malaysia. Although not all of the garbage is biomass, perhaps more than half of the energy content comes from plastics which are made from natural gas and petroleum. There are a lot of plants that generates electricity by burning all the garbage for energy and these plants are called waste-to-energy plants [6].

Pollution is a major concern with the usage of fossil fuels nowadays. Although fossil fuels have the ability to produce energy efficiently, the cost of production is relatively high and not environmental friendly. As a substitute, dry leaves are used as raw materials to produce biofuels energy. The leaves being environmental friendly and having low cost compared to fossil fuels are the main criteria for this dry leaves application and thus, it is a renewable energy source of energy, result in an effective way to produce energy. However, the issues with Malaysia to develop biomass energy is that since this energy is still new and thus, the implementation of this idea requires support from the government and subsidizes to move forward since the cost for this process is quite high. Since the energy is still new, the required equipment and materials needed to make the process successful is still unheard of in Malaysia.

Leaves have been considered to be the most cost-effective biofuels around the world. For countries with four seasons annually, they have been using this method to convert biomass into energy for years. In America alone, up to 30 million tons of leaves end up in landfills every year [3]. In fact, leaves account for 75% of the solid waste in the world. Biofuels such as methanol and ethanol are produced from corn, which have potential to provide cleaner energy. About 20% of ethanol produced was converted into energy. This energy was then used to produced diesel, natural gas and fertilizers. They are also used in refinery industry and acts as fuels to the machineries [3].

Leaves are tremendously abundant and could provide an unlimited and naturally renewable energy source. Leaves can also act as a secondary fuel in coal-burning power plants. These leaves can be transformed into energy by using a low temperature mechanism method that involves conversion process such as Pyrolysis and Torrefaction. It can provide fuels to produce electricity in power plant and thus, the potential seems to exist for tree leaves to emerge as a new, renewable energy source. Bio-fuels have been proven to be a necessity to the world. Other than source of energy, bio-fuels also can act as fuels to most of the transportation that exist nowadays.

II. METHODOLOGY

The simulation study of pyrolysis and torrefaction were done in this research study. After that, an economic assessment is done to calculate the cost of process plant to compare both of the technologies mentioned. The process flowchart of the process is shown in Figure 1.

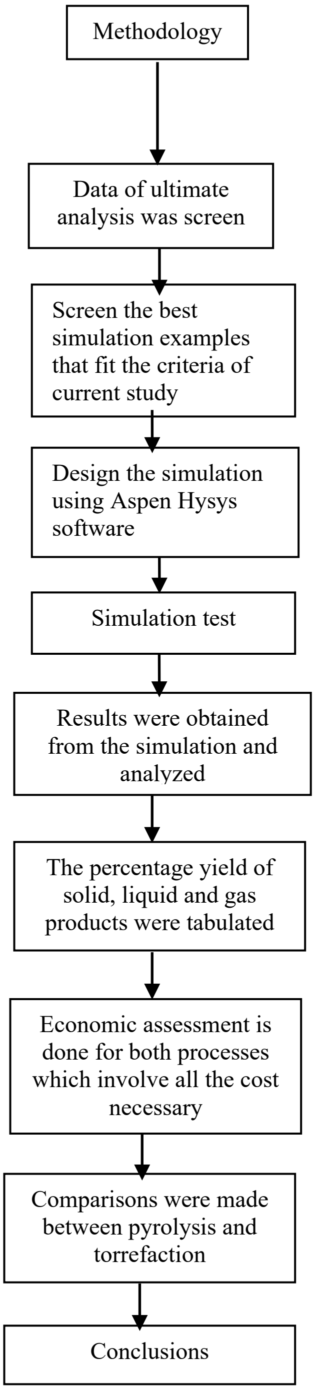

Figure 1: Process flow diagram for research methodology

A. *Determining the feedstock Ultimate analysis*

Ultimate analysis is a method that is used to obtain the percentage of constituent elements of a chemical substance such as carbon, hydrogen, nitrogen, sulfur, and oxygen. The values of the ultimate analysis were obtained that involves dry leaves as their raw materials. The ultimate analysis of dry leaves is shown in Table 1.

Table 1: Ultimate Analysis Of Dry Leaves [4]

Components	Wt%
C	52.15
H	6.11
N	6.99
S	0.16
O	30.34
Ash	4.25

B. *Simulation of pyrolysis process*

Simulation process of pyrolysis was done using Aspen Hysys software. The main objective of this simulation is to find the yield of char, biofuels and syngas that can be obtained by using pyrolysis and torrecfaction technology. Pyrolysis can be categorised into 3 types depending on the temperature used during the whole process which were slow pyrolysis, fast pyrolysis and flash pyrolysis. As for this process, slow pyrolysis is chosen since the temperature was maintained at 430°C [9]. Slow pyrolysis was also compared with torrefaction process. The sizes of the raw materials was assumed to be 20mm after going through pre-treatment before entering the dryer at a flowrate of 50kg/h and process time of 2 hours [8]. The ultimate analysis of the leaves was selected as shown in Figure 2.

C. *Simulation of Torrefaction process*

The torrefaction process was also done via Aspen Hysys. The same feedstock was used which are dry leaves. The simulation of the process was done using Aspen Hysys and the operation was done with a temperature of 200°C and 2 hours of contact time. This is because this temperature can produce the most yield of products up to 90% in total [7]. Higher than 200°C may cause destructive drying and result in lower yield of products. The process considers a plant with a directly heated reactor for torrefaction, fired heater that utilize combustion, a separator and a heat exchanger.

D. *Economic Assessment*

The economic assessment was done to find out the requirement cost to run the plant. It involves finding fixed capital cost, operating cost and total capital cost for both technologies. The fixed capital cost need to be calculate first where it can be defined as the inside battery limit (ISBL) consist of cost for equipment such as reactors, heat exchangers, distillation column and separators. The outside battery limit (OSBL) also need to be calculated which consist of cost of yards, roads and other general facilities [10]. The normal default value of OSBL is usually 20% ISBL. Total of ISBL and OSBL will be the fixed capital cost for the plant process. Plant capital is the fixed capital cost adding with the working capital while the operating cost is the total of direct and indirect cost with raw materials cost and administrative cost. To serve this purpose, the equipment that are completed in the simulation will act as a guideline to find out the equipment purchases cost necessary.

III. RESULTS AND DISCUSSIONS

A. *Pyrolysis Simulation Results*

The simulation results are shown in Figure 3 where the equipment involved in the simulation were a reactor, cyclone separator, air cooler, water cooler and a separator. The simulation was done at 430°C and 2 hours contact time since slow pyrolysis was used. The yield of the process is shown in Table 2.

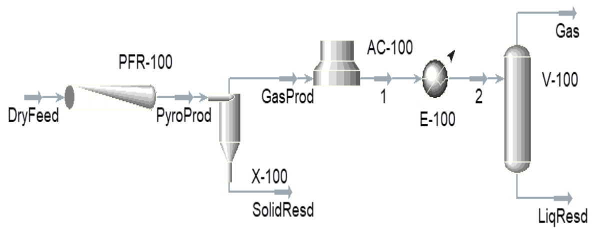

Figure 3: Aspen simulation of pyrolysis process

Table 2: Products yield for pyrolysis process

Products	**Yield (wt% Bio Product / Kg Biomass)**
Char (charcoal)	23.4%
Oil (bio-fuels)	48.8%
Gas (Syngas)	27.8%

The percentage yield of oil, gas and char being 48.8%, 27.8% and 23.4% respectively. These values may change according to the temperature and process conditions that are used in the simulation. These results are in qualitative agreement with the effect of pyrolysis vapor residence time on the yield of pyrolysis products. However, the yield of char in this simulation is quite low compared to other previous studies as shown in table 3. This is because a slow pyrolysis usually focuses on the char as the main product. The yield should be higher. This may also because different raw materials were used. The yield of the products depends greatly on the ultimate analysis which differ from the previous studies and thus, affecting the yields. However, the values are not so far away apart from other studies.

Table 3: Comparison of yields from previous study [11]

Products	Current study	Previous study
Char (%)	23.4	31
Oil (%)	48.8	40
Gas (%)	27.8	29

B. *Torrefaction Simulation Process*

The torrefaction process simulation was also done using Aspen Hysys software. The operation was done with a temperature of 200°C and 2 hours of contact time. This is because this temperature can produce the most yield of products up to 90% in total [7]. Higher than 200°C may cause destructive drying and result in lower yield of products. The equipment that involved in this process were; a reactor, cyclone separator, combustor or fired heater, a cooler and finally a separator. Figure 5 shows the result of Aspen simulation of the torrefaction and Table 3 is the yield products that was obtained from the simulation studies.

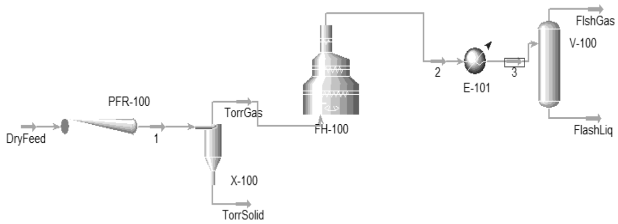

Figure 5: Aspen simulation for torrefaction

Table 4: Products yield for torrefaction process

Products	**Yield (wt% Bio Product / Kg Biomass)**
Char (charcoal)	70.36%
Oil (bio-fuels)	11.51%
Gas (Syngas)	18.13%

The results obviously show that the process is expected to be producing more char products compared to oil and syngas which range from 70.36%, 11.51% and 18.13%, respectively. This is because the temperature is maintained at very low range and resulted in destructive drying. However, the result shows that the expected values for this simulation is a bit different from the previous studies as shown in table 5. This may happen due to errors in values input during the simulation. Since the literature for verification is very limited, some input variables that are required often not given and some of the input variables are taken from other sources, resulting in mix references input variables in a single simulation. This may cause the products yield to be different from the expected one. Since the source of validation is finite, some of the simulation values input had to be changed to fit the circumstances. The difference in raw materials and difference operating conditions may also be the cause for this matter too.

Table 5: Comparison of yield from previous study. [1]

Products	Current study yield (%)	Previous Study yield (%)
Char (charcoal)	70.36	77.40
Oil (bio-fuels)	11.51	10.64
Gas (Syngas)	18.13	11.96

C. Economic Assessment

Economic assessment will be divided into two which the first one consisting all the necessary calculation for pyrolysis and the next one for torrefaction. The main objective of this assessment is to find out and calculate the fixed capital cost, operating cost and total capital cost. All the equations and formulas used for this calculation are stated below:

ISBL = equipment purchases cost * 5 (1)

OSBL = ISBL * 20% (2)

The fixed capital = ISBL + OSBL (3)

Plant Capital Cost = fixed capital cost + working capital (4)

Operating cost = Fixed capital cost + raw materials + administrative cost (5)

The calculation was done to compare the operating and plant capital cost for both technologies based on their processes. The results are shown in table 6.

Table 6: the operating and plant capital cost for both technologies

Processes	Pyrolysis	Torrefaction
Plant capital cost	RM 18,754,908	RM 19,594,848
Operating cost	RM 23,755,588	RM 24,679,012

the comparison can now be made for both of the technologies. As calculated above, the torrefaction process needs more plant capital cost and operating cost compared to pyrolysis process. However, the yield of biochar is much higher for torrefaction process compared to pyrolysis process. In terms of cost, torrefaction is slightly higher than pyrolysis but with the yield it can produced, torrefaction can be seen as a better and more efficient method to do rather than slow pyrolysis.

IV. CONCLUSION

Pyrolysis and torrefaction have the same purpose in mind which are to convert biomass into sources of energy that can be used in daily life. , torrefaction seems to yield more biochar compared to pyrolysis with the same amounts of feedstocks where torrefaction yield 70.36% while pyrolysis only yield 23.4% of biochar. Although the differences seems to be very huge, it is also important to note that pyrolysis also produced bio fuels in a large quantity of yield and this bio fuels with a value of 48.8% compared to torrefaction with 11.51% only. Bio fuels can also be sold in the market for a high price. Economic wise, torrefaction process requires more cost to operate with plant capital cost value of RM 19,594,848 and operating cost of RM 24,679,012 compared to pyrolysis that requires RM 18,754,908 plant capital cost and RM 23,755,588 operating cost. The difference margin between both process is small with torrefaction being a little bit higher. The values obtained are assumed to be not affected by the depreaciation value or economic changes. The factors of different raw materials that are used in the feedstocks also needs to be considered since the lignin, cellulose and hemicellulose content and their ultimate analysis content will affect the process and the yield of products that will be produced. In a nutshell, both technologies have their own benefits and disadvantages. However, if the main targeted product is charcoal, torrefaction process is the preferred method.

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REFERENCES

[1] Anukam, A., Mamphweli, S., Reddy, P., Okoh, O., & Meyer, E. (2015). An Investigation into the Impact of Reaction Temperature on Various Parameters during Torrefaction of Sugarcane Bagasse Relevant to Gasification. *Journal of Chemistry*. https://doi.org/10.1155/2015/235163

[2] Biswal, M., Banerjee, A., Deo, M., & Ogale, S. (2013). From dead leaves to high energy density supercapacitors. *Energy & Environmental Science*, *6*(4), 1249. https://doi.org/10.1039/c3ee22325f

[3] Boman, U. R., & Turnbull, J. H. (1997). Integrated biomass energy systems and emissions of carbon dioxide. *Biomass and Bioenergy*, *13*(6), 333–343. https://doi.org/http://dx.doi.org/10.1016/S0961-9534(97)00043-3

[4] Kaiser, E. R. (1966). Chemical Analyses of Refuse Components. *Proceedings of 1966 National Incin. Conference*, 84–88.

[5] Koh, M. P., & Hoi, W. K. (2003). Sustainable biomass production for energy in Malaysia. *Biomass and Bioenergy*, *25*(5), 517–529. https://doi.org/10.1016/S0961-9534(03)00088-6

[6] Tabasová, A., Kropáč, J., Kermes, V., Nemet, A., & Stehlík, P. (2012). Waste-to-energy technologies: Impact on environment. *Energy*, *44*(1), 146–155. https://doi.org/10.1016/j.energy.2012.01.014

[7] Tumuluru, J. S., Sokhansanj, S., Hess, J. R., Wright, C. T., & Boardman, R. D. (2011). A review on biomass torrefaction process and product properties for energy applications. *Industrial Biotechnology*, *7*(5), 384–401. https://doi.org/10.1089/ind.2011.0014

[8] Visconti, A., Miccio, M., & Juchelková, D. (2015). An

aspen plus® tool for simulation of lignocellulosic biomass pyrolysis via equilibrium and ranking of the main process variables. *International Journal of Mathematical Models and Methods in Applied Sciences*, *9*, 71–86.

[9] Yang, Y., Heaven, S., Venetsaneas, N., Banks, C. J., & Bridgwater, A. V. (2018). Slow pyrolysis of organic fraction of municipal solid waste (OFMSW): Characterisation of products and screening of the aqueous liquid product for anaerobic digestion. *Applied Energy*, *213*, 158–168. https://doi.org/10.1016/j.apenergy.2018.01.018

[10] Yusuf, N. N. a N., & Kamarudin, S. K. (2013). Techno-economic analysis of biodiesel production from Jatropha curcas via a supercritical methanol process. *Energy Conversion and Management*, *75*, 710–717. https://doi.org/10.1016/j.enconman.2013.08.017

[11] Anssi Källi, Vesa Arpiainen, Taisto Raussi & Sylvia Larsson (2014). Evaluation of Mobile Slow Pyrolysis Process and its Products from various Raw Materials