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STUDY OF BIOMASS COMBUSTION PERFORMANCE AND PLANT FEASIBILITY OF BIOMASS-BASED HYDROGEN GENERATION

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ABSTRACT

Energy becomes the major problem due to the decrease of fossil fuel production which will run off in the next few years. Currently, the development of renewable energy is regulated by Presidential Decree No.5 / 2006 regarding the national energy policy. One of the energy sources that potential to be developed is biomass energy. Indonesia has a large new and renewable energy potential which includes 50 GW of Biomass which can be raised from agricultural industry waste such as palm empty bunches. In 2010, the production reached 49.3 million tons of palm oil bunches and about 23% of the total bunches will become waste as empty bunches. One, which is addressed in this paper, is the research study of biomass potential as renewable energy source that environmentally friendly observed from its CO emissions and also ignition time and temperature. The shortest ignition time is occurred at combustion involving bio-briquettes of 100% biomass content with superficial air velocity at 0.42 m/s (0.5 minutes). The lowest CO emission was obtained by burning bio-briquettes of 100% biomass content with 0.54 m/s superficial air velocity (average 312.81 ppm). Furthermore, the preliminary study of biomass plant development is also conducted to see the feasibility of its establishment according to the economic approach such as investment, sensitivity analysis, etc. The results of this study will show whether biomass development in Indonesia can be implemented or not, which then become a potential consideration for Indonesia to develop biomass as new energy source in the future.

Keywords: Renewable Energy, Biomass, Plant Development.

INTRODUCTION

On facing the global energy challenge in the future, it becomes a long-term plan for Indonesia to develop new and renewable energy sources. On the other hand, the reduction of carbon gas emissions became the agenda which is very important in terms of the green environment issue. It is well known that one of the effects of global warming which is currently perceived is a significant change in the Earth's climate, so that it can encourage the effort in looking for a renewable energy which is clean and environmentally friendly.

Currently, the development of renewable energy is regulated by Presidential Decree No.5 / 2006 regarding the national energy policy [1]. One of the energy sources that potential to be developed is biomass energy. Biomass is everything that comes from nature including living plants and organic waste from animal waste, plants, and humans.

Indonesia has a large new and renewable energy potential which includes 50 GW of biomass which can be raised from agricultural industry waste such as palm empty bunches. Indonesia now becomes the biggest palm oil producer in the world. In 2010, the production reached 49.3 million tons of palm oil bunches. This amount is more than that in 2009 which increase 13.9% and cover almost half of world palm oil production [2].

Empty fruit bunches of oil palm is one of the by-product in the form of solids from palm oil processing industry. Availability of oil palm empty fruit bunches is significant when viewed by an average production of oil palm empty fruit bunches to the total amount of processed fresh fruit bunches (FFB). Average production of oil palm empty fruit bunches is about 22% to 24% of the total weight of fresh fruit bunches processed at a palm oil mill [3]. This amount is very potential for oil palm empty bunches to be used as biomass for producing new energy.

Biomass can be utilized in several ways. Biomass can be used to supply heat for household cooking by forming it as briquettes or pellets and also be converted to produce electricity and mechanical energy which are necessary to support our daily activities at home, office, or industries. Characteristics of biomass burning closely related with characteristics of the biomass. Proximate analysis conducted to determine levels of fixed carbon, volatile matters, moisture content, and ash from biomass. From the results of proximate analysis, it is known that the fixed carbon content of palm empty bunches that has been dried is very low (17.45%) and still have a high water content (58.6%) so that its heating value to be low enough [4]. However, palm empty bunches contain a high volatile matter (68.67%).

Volatile matter combustion can generate heat which is potential to shorten the time of ignition.

In this study, biomass from oil palm empty bunches is observed as bio-briquettes to examine its performance. Bio-briquette combustion characteristics will be evaluated based on the time of ignition and emissions resulting from combustion bio-briquette. Furthermore, preliminary study of biomass plant development is also conducted. The results of the study will show us whether biomass can be used as Indonesia's future energy to substitute the conventional energy used which is depleted from year to year.

2. METHOD

This paper consists of two methods, the laboratory experimental to observe biomass performance and preliminary study of plant design for hydrogen fuel production (biomass to hydrogen).

2.1 Experimental Method

Before the observation, the bio-briquettes are made by mixing palm empty bunches and coal to see the influence of biomass content to its performance. Palm empty bunches and coal in advance through the stages of preparation, namely the enumeration process into powder and fibers pass 20 mesh of size. After enumeration process, palm empty bunches and coal are then dried by using oven at a temperature of 105 ° C for 6.5 minutes. Then, palm empty bunches and are mixed with tapioca to form bio-briquettes. Palm empty bunches content is varied at 50%, 75%, and 100%. After that, the mixture of coal and PEB formed on the mold with a diameter of 4 cm using hydraulic presser. Mixture of coal briquettes and PEB are then dried for 2 days. The equipment configuration is shown in Fig. 1.

The configuration consists of several main tools such as combustion stove equipped with blower in the bottom side to supply updraft forced air, thermocouple, acquisition data logger connected to computer, and CO analyzer. Stove is placed in combustion room and exhaust system is attached so flue gas from combustion could directly exhausts to the environment. PC, data logger, and gas analyzer is placed outside the combustion room. The stove and data logger is connected by thermocouple while stove and gas analyzer is connected by copper pipe. Finally, the flue gas was pumped by peristaltic pump that connect to the gas analyzer to help flue gas enter the pipe.

There are three objects of observation in this experiment, such as ignition temperature, ignition time, and CO emission (Koestoer, 1997). Ignition temperature is taken by burning briquettes independently on alcohol heater. Briquettes are burned to form a flame and then the temperature is taken. Temperature which the flame formed is taken as the ignition temperature of the briquettes burning in a stove. Ignition time test is done by using a thermocouple attached to the Data Logger. Thermocouple is placed in the briquette that is located closest to the promoter on the second layer. Data Logger will record the combustion temperature data every 10 seconds. Ignition time is defined as the time required to reach the ignition temperature. CO emission measurement performed on the flue gases of combustion every 1 minute. Combustion flue gas is concentrated into a copper pipe which is connected with a peristaltic pump hose and aim to reduce the temperature of flue gas to comply with the terms of the temperature on the gas analyzer.

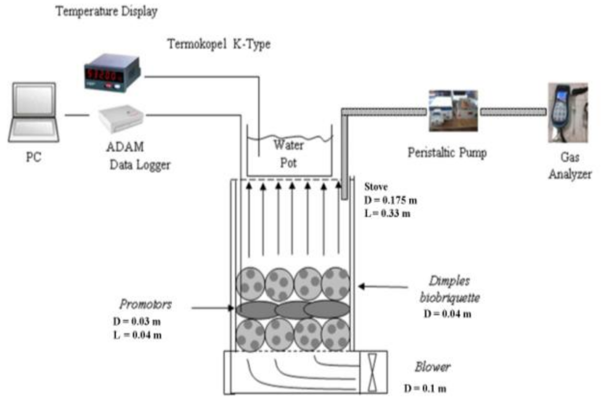

Fig.1. The Experimental Set Up with Data Collection Scheme

2.2 Feasibility Study of Plant Development

The study is started by simulation conducted to design the process of biomass to hydrogen plant. The simulation uses Hysis V7.1 which is functioned to design the operating condition and results the feed-to-product process. The study is then followed by the analysis of economic of the plant. The economic analysis is conducted to see the total capital investment of the process design by using Modular Guthrie Method. Furthermore, the study is continued by economic scenario and feasibility to show whether the plant is possible to be implemented or not. The scenario including scale up of the plant is made by using Six Tenth Rules method. This scenario is conducted to see the possible price of crude hydrogen fuel and also the feasibility by looking the Capital Charge Factor (CCF) of the plant.

3. RESULT AND DISCUSSION

This section will explain the experimental and also preliminary study of plant development of biomass as new energy source in Indonesia. The performance observed which consist of ignition and also emission is tested to see the potential of biomass as new energy used as briquettes for small scale application. For plant scale, biomass is converted into hydrogen energy. Hydrogen is new energy which is environmentally safe and will be the future energy substitute. The preliminary study is conducted which includes economic and feasibility consideration of biomass plant development in Indonesia. The result of the feasibility study will show the potential of biomass to be developed massively.

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3.1 Biomass Ignition Time and Temperature

Ignition time is time of the entry of fuel until the flame is formed at a temperature of ignition [5]. Ignition temperature is the temperature when the flame begins to flare from the fuel. The composition of palm empty bunches in bio-briquettes and superficial velocity of gas influence the temperature and time of ignition as shown in Table 1.

Table 1: Ignition Time and Combustion Temperature for Each Superficial Velocity and Biomass Content

Superficial velocity	Composition	Ignition temp. (◦C)	Ignition time (min.)	Highest combustion temp. (◦C)
0,29 m/s	50% PEB	280	6,6	342,9
	75% PEB	187	1,1	347,5
	100% PEB	154	0,6	574,8
0,42 m/s	50% PEB	280	2,2	620,8
	75% PEB	187	0,8	494,2
	100% PEB	154	0,5	399,4
0,54 m/s	50% PEB	280	1,8	579,8
	75% PEB	187	0,7	836,2
	100% PEB	154	0,6	523,7

Addition PEB (Palm Empty Bunches) as a mixture of biomass briquettes can shorten the time of ignition of bio-briquettes. Short ignition time is influenced by the content of volatile matters are owned by the biomass. Volatile matters content of biomass is higher than coal as shown in Table 2. The higher volatile matters content of the biomass will facilitate the ignition process and shorten the time of ignition.

Table 2 : Proximate Analysis of Biomass and Coal

Parameters	PEB	Coal	Method
Moisture Content (%wt/adb)	1.64	12.71	ASTM D-5142
Volatile Matters (%wt/adb)	65.86	41.03	
Fixed Carbon (%wt/adb)	15.56	42.38	
Ash (%wt/adb)	4.88	3.89	

Source: BPPT (4A/LabJabek/B2TE/BPPT/IV/12)

From Table 1 can be seen that the higher the superficial velocity of air will shorten the time of bio-briquettes ignition. Greater superficial velocity will affect the air supply in the stove. Velocity range in this study (0.29 m / s, 0.42 m / s, and 0.54 m / s) is the safe velocity range, where the addition of superficial air velocity will increase the air supply in a stove. Superficial velocity is calculated by the following equation:

$$v_{\text{superficial}} = \frac{A_{blower}}{A_{stove}} v_{average} \qquad (1)$$

Where $v_{average}$ is the inlet velocity measured in the blower, and A is the surface area for both blower and stove. Increasing the air supply in the stove will give good effect to shorten the time of bio-briquettes ignition. The increase of air supply means the increase of oxygen, which is an indispensable element of combustion in the stove. When oxygen supply approaches the needs for combustion, reaction occurred will lead to perfect reaction and result in higher exothermic heat to trigger the ignition. In addition of air supply, the increase superficial velocity means an increase in Reynolds number of air flow.

3.2 CO Emission of Bio-Briquettes Combustion

CO emission measurements carry out at some point of the cumulative output of flue gas. CO emissions will have a peak amid the burning caused by arson which has led to the burning char. The burning of the solid phase can reduce the surface temperature of briquettes that have impact to the bed so the temperature decreases and conversion of CO to CO_2 becomes slow.

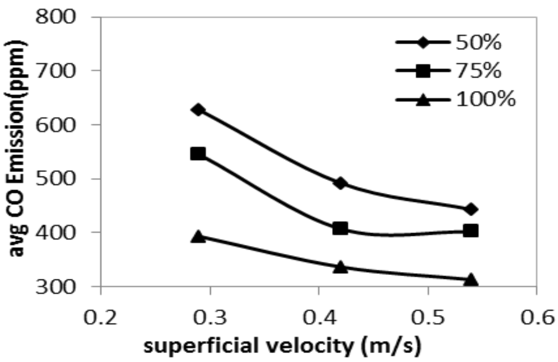


Fig. 2. Effect of Superficial Velocity and Biomass Content to the Average of CO Emissions

As shown in Fig. 2, the addition of biomass briquettes will lower the average rate of CO combustion. This is presumably due to the fixed carbon content of biomass is much less than content of coal. Fixed carbon is the main component of the formation of CO. With less fixed carbon contained in briquettes, the formation of CO will be lower. Furthermore, biomass has greater volatile matters content than coal. Volatile matters, besides can shorten the time of ignition, it is also good for conditioning the reaction of conversion of CO to CO_2. It is because the combustion of volatile matter results higher heat than combustion of solid phases that involve conduction heat transfer by briquettes volume. Finally, the higher the content of biomass briquettes will influence the turbulence of air through the surface of briquettes because of its roughness. The higher turbulence will make the convection heat transfer will be better and may increase bed temperature. The increase in temperature will support the formation of CO_2 which then reduce the CO emission.

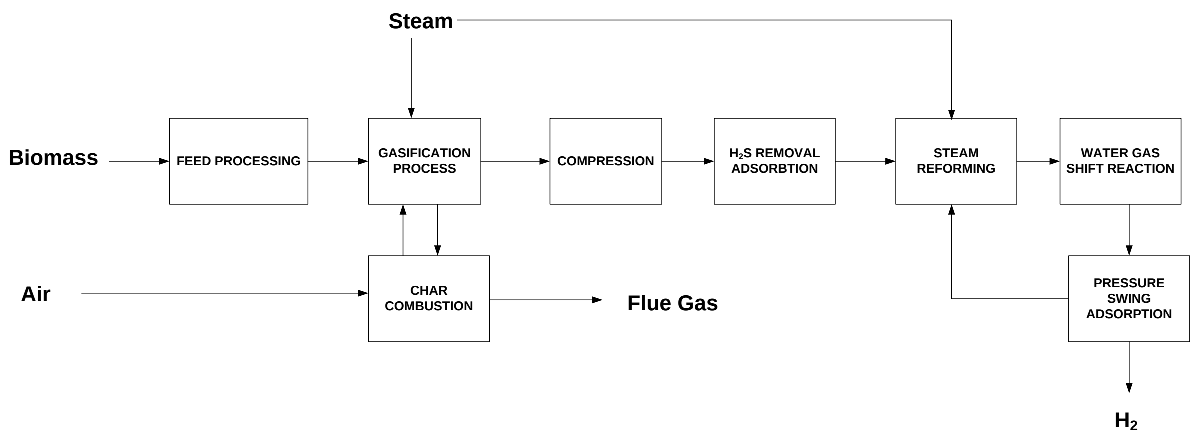
From Fig. 2, it can be seen that the addition of air superficial velocity will reduce the emissions of CO from combustion. This is caused by the greater air of combustion is based on the measured flame temperature relative to ambient conditions. Assuming that the mass of flue gas burned is same as mass of air supplied and specific heat value (C_p) used is C_p for air, will result the calculation of combustion enthalpies in Table 3.

Table 3: Combustion Enthalpy Calculation

Composition	Q (kcal) for each superficial velocity		
	0.29 m/s	0.42 m/s	0.54 m/s
50% PEB	5,052.19	18,860.30	24,431.77
75% PEB	5,281.77	10,258.92	44,356.49
100% PEB	8,780.40	14,092.88	21,580.29

Based on Table 2 above, there is tendency that the increase of velocity will result to the increase of enthalpy for each composition. It is shown that at high velocity of air, the supply of air to stove becomes greater and may cause better combustion than that at lower velocity. Perfect combustion will result higher combustion heat which is determined by greater enthalpy. Furthermore, perfect combustion will produce less CO emission because the flame formed at higher velocity of air will produce heat of convection. This heat will cause the inside temperature becomes higher and CO_2 formation will be faster which then make the CO emission lower.

total empty bunches. Furthermore, drying is also conducted to meet the specification of feed for gasification process (small amount of water content) [7]. The next step is gasification process to convert biomass into gas such as H_2, CO, H_2S, and other hydrocarbons. The gasification is conducted at 843.3^{o}C and 158.6 kPa. The gas from gasification is then cooled and compressed to meet the temperature and pressure specification for acid removal process (about 3,162 kPa and 196^{o}C) and solid residue of gasification is then burned to supply heat for gasification. H_2S removal process used vessel with iron sponge as adsorbent which will bond H_2S gas and results pure gas which then goes to syn-gas reforming process. In reformer, hydrocarbons are reacted with steam to produce CO and H_2. The reactor runs at 990^{o}C and 3,034 kPa of temperature and pressure respectively. CO produced from reformer is then reduced by following further reaction in water gas shift reactor. This reactor is aimed to convert CO and produce more H_2 by reacting with steam. Water gas shift process contains two reactors, one reactor runs at higher temperature (350^o – 600^{o}C) and the other one at lower temperature (150^o – 300^{o}C). The product is now mostly hydrogen. Before the hydrogen ready to be used, it must be purified at pressure swing adsorption process to clear the polluter. The hydrogen produced from Hysis V7.1 simulation is 208.5 kg/hour or 25 mJ/hour on energy basis from 5 tons of biomass per hour. Fig. 3 shows the process diagram of hydrogen production from biomass which consist of several production units.



3.3 Study of Biomass to Hydrogen Plant Process

Production process of hydrogen from biomass consists of several stages such as feed processing, gasification, Acid removal, syn-gas reforming, water gas shift process, and product purification by pressure swing adsorption [6]. The process is started by feed processing. In this stage, the palm empty bunches as biomass is crushed into small particles and then dried to reduce the air content which is more than 50% of the

3.4 Economic Consideration of Biomass to hydrogen Plant

In the feasibility study of biomass plant development will be explained about Total Capital Investment (TCI) calculation, economic scenario, and feasibility. There are several assumptions used in this study, such as:

- Equipment cost is a cost in a variation of time. Hence, the cost used is based on year 2012 by using CE Index.

- The plant is run in 330 days per year.
- IRR (Internal Rate of Return) used is 15%, or 0.15.
- Cost is in USD ($).

Total Capital Investment calculation can be done by using many ways. In this paper, the method used to calculate the TCI is Modular Guthrie method which can be formulated by the Equation 2 [8].

$$C_{TCI} = 1.18(C_{TBM} + C_{site} + C_{building} + C_{offsite\ facilities}) + C_{WC} \quad (2)$$

Where C_{TCI} is total capital investment cost, C_{TBM} is total bare module cost, C_{site} is site development cost, $C_{building}$ is building establishment cost, and $C_{offsite\ facilities}$ is offsite facilities development cost.

Total bare module cost can be calculated by summing all bare module cost of equipment used in the process. The calculation of TBM cost is started by calculating purchase equipment cost from all equipment in the year basis of 2012. The cost in 2012 is forecasted by using CE index. The bare module cost can be expressed by the Equation 3 below and shown in Fig. 4.

$$Total\ Bare\ Modul\ Cost = \sum Bare\ Modul\ Cost \quad (3)$$

Site development cost is a cost to develop site. The type of the site is grass root plant with the amount of the cost is about 10 – 20% of total bare module cost. Building cost is a cost to build a building outside the process area in the plant. Building cost for non-process of grass root plant is about 20% of total bare module cost. Offsite facilities cost can be calculated by summing the utility cost and 5% of total bare module cost. Contingency is about 15% of TBM cost and contractor fee is about 3% of TBM cost. Working Capital Cost (C_{WC}) can be calculated by using following equation.

$$C_{WC} = 0.176 \times 1.18(C_{TBM} + C_{site} + C_{building} + C_{offsite\ facilities} \quad (4)$$

After calculating the component of Total Capital Investment cost, the TCI amount can be achieved by adding all of the components. The result from the calculation is shown in the following Table 3 and the breakdown of the TCI cost is shown in Fig. 5.

After calculating the cost of plant investment, the next step is considering the decision whether the process design of GTL plant is feasible to be implemented or not which can give benefits and also to look the pattern of feasibility factor when the plant is scaled up. This paper prefers to avoid trial-and-error calculations in preliminary process designs, and yet it would like to account for the time value of money in some ways in the profitability and feasibility analysis. To accomplish this goal, it can be defined the Capital Charge Factor (CCF). CCF is a factor used to measure the feasibility of new plant by assuming the minimum Rate of Return (ROR) and also payback period of the plant. CCF is also defined as formula of revenue, total production cost, and also investment (TCI) written as follow [9]:

$$\mathrm{Re}venue - Total\ Production\ Cost = CCF \times (TCI) \quad (5)$$

Table 3: Total Cost Investment Calculation

Component	Value in $
Total Bare Modul Cost (C_{TBM}) ($)	16,560,655.96
Site Development Cost (C_{site}) ($)	3,312,131.19
Building Cost ($C_{building}$) ($)	3,312,131.19
Offsite Facilities Cost ($C_{offsite\ facilities}$) ($)	936,643.49
Contingency ($)	2,484,098.39
Contractor fee ($)	496,819.68
Working Capital (C_{WC}) ($)	5,009,565.96
Total Cost Investment ($)	**36,453,927.00**

From the previous part of this paper, the TCI cost has been calculated which is US$36,453,927.00. Then, the revenue can be achieved by assuming the selling cost of hydrogen energy is $48.38/gJ with consideration that the hydrogen price is between $12 - $52/gJ at 2012 [10]. The production cost can be calculated by assuming the price of Palm Empty Bunches (Biomass) is 5$/ton, natural gas is $6.5/MMBTU, electricity is $0.14/kWh, and utility water is $0.15/ton. Those prices are considered by the actual domestic price in Indonesia per April 2012. By considering also maintenance, labor, tax, insurance, interest, and plant overhead, it can result the amount of CCF which only 0.15.

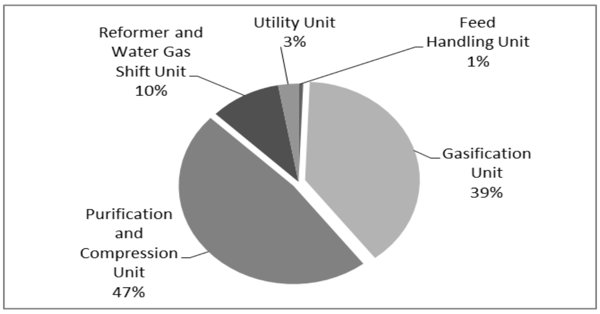


Fig. 4. Bare Module Equipment Cost Breakdown

For a new project, a minimum CCF number for the plant to be said potentially feasible is 0.33. This value is calculated based on the minimum Discounted Cash Flow Rate of Return (DCFROR) which is 15% for and expected payback period which is 11 years for the new project (Douglass, 1988). Basically, the 0.15 for CCF in this plant design can be said not feasible. But, by doing the scale up projection of the plant, we can get the relation of CCF with production capacity as shown in Fig. 6 below.

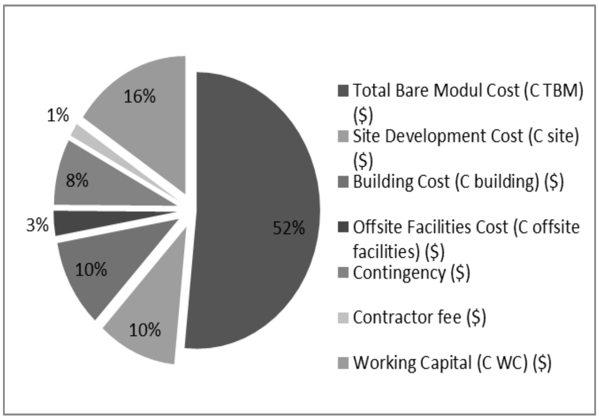


Fig. 5. Total Capital Investment Breakdown

From the Fig. 6 above, when the production capacity increase, the number of CCF is also increase which makes the plant become very feasible to be implemented because the CCF is bigger than 0.33. While the CCF bigger, the payback period relationship can be achieved by using the Equation 6 [9] with *i* is rate of return (i = 0.15 is the smallest value for a new project) and *N* is payback period of the plant development, and the result is the payback period become faster when the production capacity bigger (Fig. 7). From the CCF and payback period graphs, it is shown that the plant design is feasible and even potential to be developed when the production capacity is more than 1,200 kg/hour of hydrogen.

$$CCF = \frac{[0.25(1+i)^4 + 0.295i - 0.298](1+i)^N - 0.225i + 0.048}{0.676[(1+i)^N - 1]} \quad (6)$$

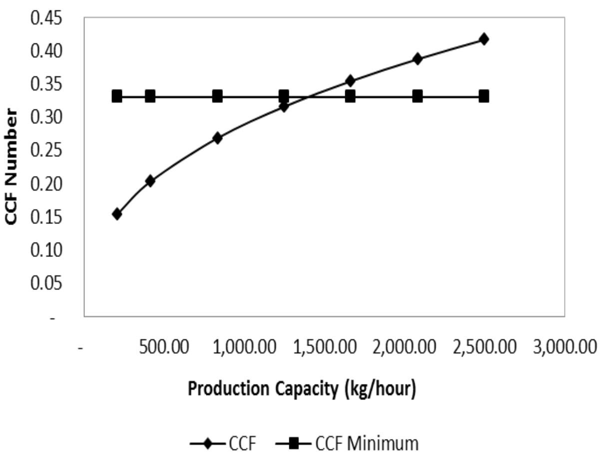


Fig. 6. Capital Charge Factor Number

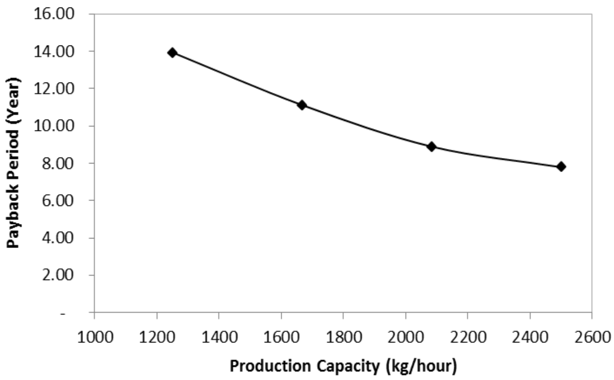


Fig. 7. Payback Period per Production Capacity

5. CONCLUSION

On facing the global energy challenge in the future, it becomes a long-term plan for Indonesia to develop new and renewable energy sources. New energy source that is potential to be developed is biomass. From this paper, the biomass (palm empty bunches) performance which include ignition time, temperature, and CO emission is examined. Also, the preliminary study of biomass to hydrogen plant development is conducted. The addition of biomass in briquettes can shorten the ignition delay. In this study, the shortest ignition delay occurs by burning bio-briquettes with 100% biomass content at superficial air velocity 0.42 m / s, which is 0.5 minutes. Furthermore, the addition of biomass in briquettes can reduce the average CO emissions formed, while the lowest average CO emissions generated in the combustion bio-briquettes with 100% biomass content at 0.54 m / s, which is 312.81 ppm. From the preliminary study of the plant development, TCI cost of the plant is $36,453,927.00. This value is considerable based on the projection of TCI cost study. The feasibility study of the plant stated that the production capacity of 208.5 kg/hour is still not feasible enough to be implemented. But, after doing the scale up projection of the design, the number of CCF is also increase which makes the plant become very feasible to be implemented and will give a lot of benefits from its development. Finally, the design results new energy produced which is environmentally cleaner than conventional fuel which can be a solution for Indonesia energy problem.

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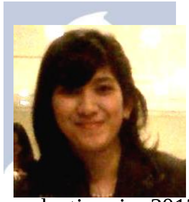

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