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Sustainable and Renewable Energy from Biomass Wastes in Palm Oil Industry: A Case Study in Malaysia

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ABSTRACT

Palm oil is one of the most important oils in the world and huge amounts of palm biomass wastes are generated through palm oil extracting process which could endanger the environment. Meanwhile, electricity shortage is getting worse due to lack of fossil fuel. To convert biomasses from palm oil industry for power generation is a beneficial approach for both power shortage and environmental degradation. In order to investigate and optimize the generation process of power and heat from the waste biomass in palm oil industry, an analytic study of a combined heat and power plant in a palm oil mill fuelled with sustainable and renewable biomass wastes was conducted using ECLIPSE software through a case study in Malaysia. The resources of the biomass wastes in the mill were identified and the samples were collected on site. The waste samples were analyzed in laboratory and their calorific value, chemical composition and biomethane potential were found. A simulation model was then set up using ECLIPSE software and the model was validated using the practical data of the CHP plant. Three different combinations of the biomass wastes, including EFB and Shell as fuel for power generation, MF co-firing with Biogas, and power generation using KS, EFB and Biogas with preheaters, were used in the simulation. It was found that all of the three combinations were able to produce enough electrical power and heat (steam) to meet the power and heat demand for the production process. The simulation results indicated that the palm solid biomass wastes and the biogas produced by mill effluent were able to provide enough sustainable and renewable fuel for the palm oil production process; and it is possible to provide extra electricity for the nearby area, which is one of the best option for utilization of palm oil biomass wastes.

Keywords: combined heat and power biomass wastes, palm oil mill, sustainable and renewable energy

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1 Introduction

Fossil fuels are the main sources of energy used in industries today. However, the resulting shortage of energy and global warming have emerged as major problems and development of renewable and sustainable energy resource play a crucial role in human's future. Biomass energy is known as one of the most promising candidates for alternative sustainable and environmentally friendly energy resources. On the other hand, palm oil is one of the most important oils in the world's oil used as food, fats and related products, and biodiesel. A vast amount of biomass waste, including empty fruit bunch (EFB), fiber, shell, and palm oil mill effluent (POME) is generated from palm oil extracting process because of fast growing palm oil industry [1-3]. Biomass residue can be used as fuel in the boiler or be converted into organic fertilizer. Palm oil mills operate cogeneration system to produce electricity and steam for palm oil production process using solid biomass wastes as main source of energy input. Since the beginning of this century, more and more attention has been paid to related researches mainly in Malaysia, and in Indonesia, Columbia and Brazil as well [4-9]. Estimation on the potential of electricity generation based on the balance of mass and energy showed that the biomass available in the plants could generate surplus electricity than process demands [8]. The investigation on the combustion characteristics of oil palm biomass (including kernel shell, mesocarp fibre and empty fruit bunches), and coal/biomass blends via thermogravimetric analysis (TGA) indicated that co-firing of oil palm biomass and coal is possible to reduce coal consumption [10]. Many researchers focused on the social and economic feasibility and sustainability of converting oil palm biomass to bio-based commercial products, and the production and consumption of energy in palm oil mills [11-13]. Life cycle assessment was used to evaluate the environmental impacts of two palm oil production systems [14]. An analytical tool was developed which integrates cost, energy savings, greenhouse gas considerations, scenario analysis, and a Geographic Information System (GIS) to provide a comprehensive analysis for effective use of palm oil waste as energy resources [15]. Considering the main properties, quantities, and current practices, Garcia-Nunez et al [16] summarized the potential uses for biomass generated in palm plantations and at the palm oil mills. The need for development of high-value products from biomass waste and evolution of palm oil mills into bio-refineries was emphasized. Chiew et al [17] analyzed seven technologies being developed in Malaysia for utilizing oil palm residue: ethanol production, methane recovery, briquette production, biofuel for combined heat and power (CHP) plants, composting, medium density fiberboard (MDF) production, and pulp and paper production. The methane recovery and composting were found to be more environmentally friendly than other technologies. Meanwhile biogas and hydrogen production from POME and solid waste residues of palm oil mill industry has drawn a lot of interests as well [18-19]. Oil palm biomass is considered as a potential raw material candidate for hydrogen gas production

[20-21]. Optimal conditions for methane production from solid-state anaerobic digestion of oil palm biomass was investigated as well through adjusting total solids contents, feedstock to inoculum ratios and carbon to nitrogen ratios [22]. A novel technique has developed to enhance hydrogen and methane production from palm oil mill effluent using two-stage thermophilic and mesophilic fermentation [23]. Kanchanasuta et al found that the presence of the sludge seed in palm oil decanter cake appeared to facilitate both hydrolysis and methanogenesis [24]. However, low colorific value of biogas, presents of corrosive gases in biogas combination and high costs of biogas purification are main obstacles for the development of biogas utilization. A lab-scale flameless combustion furnace was adopted and the performance of flameless combustion chamber fueled by biogas showed that flameless combustion is one of the best feasible strategies for biogas utilization [25]. The characteristics of biogas under various combustion regimes in combined heat and power generation system also proved this point [26]. It was found that the rate of power generation increased when adding a small amount of hydrogen into biogas using self-preheated reactor in combustion system [27].

However, a few reports concern specific analysis and optimization for effective utilization of biomass combined heat and power in a palm oil mill. It is necessary to investigate and optimise the generation process of power and heat from the waste biomass in palm oil industry through a case study. In this work, a simulation and optimization study of palm oil biomass combined heat and power plant were conducted using ECLIPSE software in one of the palm oil mill in Malaysia as Malaysia is one of the largest palm oil producing country.

List of abbreviation

FFB	Fresh Fruit Bunches
EFB	Empty Fruit Bunch
CPO	Crude Palm Oil
POME	Palm Oil Mill Effluent
MF	Mesocarp Fibre
KS	Kernel Shell
BMP	Biomethane Potential
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
ECLIPSE	European Coal Liquefaction Process Simulation and Evaluation

2 Methodology

2.1 Combine Heat and Power (CHP) System analysis

A palm oil mill in Sabah, Malaysia was selected as a case study. The objective of the palm oil mill is to extract Crude Palm Oil (CPO) from the Fresh Fruit Bunches (FFB). FFB were harvested and collected from oil palm plantation and transported to palm oil mill collection point. The chosen palm oil mill had a capacity of processing 60 tonnes of FFB per hour or 16.67 Kg/s of FFB, it could be varying depends on the season of oil palm. The average operating hours per year was nearly 4400 hours. Normally the processes of the palm oil mill include sterilization, stripping, digestion and pressing, clarification, purification, drying and storage. About 3.67kg/s of CPO was produced under above-mentioned process. The palm oil mill adopted 'wet processing method' where large amount of water and steam is used in several stages. Fig.1 shows the process flow diagram of the existing palm oil mill CHP modelled in ECLIPSE. Fiber and dry shell from production process were used as fuel for biomass water-tube boiler to produce heat and power through steam. Clean water was pumped into the water tubes in the boiler at the flow rate of 9 to 9.5Kg/s. Heat from combustion chamber heated the water tubes to produce saturated steam at temperature of about 222℃at 23 Bar. Saturated steam was used to power a back pressure steam turbine generator with installed capacity of 1.6MW. Actually under normal mill operation of processing 60 tons per hour of FFB, about 1.3MW of electricity was produced and required. The steam turbine generator expanded and discharged the steam at about 143℃ at 3.5 bar, which then was channeled to a steam manifold for utilization in various production process.

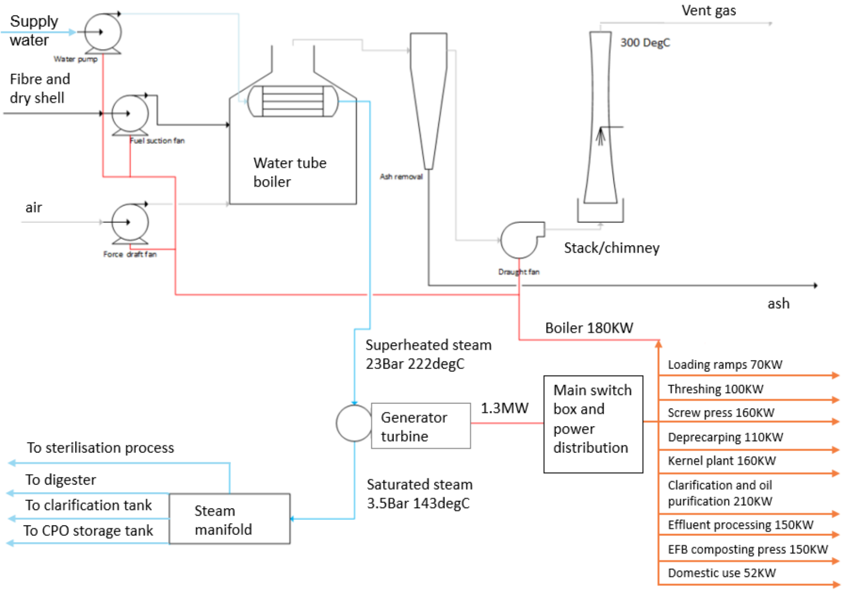

Fig. 1. Process flow diagram of combined heat and power system with biomass boiler

2.2 Biomass waste analysis

In the chosen mill, 22 to 24% of Empty Fruit Bunches (EFB) could be obtained from FFB, so the output of biomass waste was about 3.9 kg/s of EFB, along with about 3.1kg/s of Mesocarp Fibre (MF) and1.22 kg/s of Kernel Shell (KS). MF and 50% KS were mixed with air and fed into biomass boiler as fuel. Another 50% KS was collected and stored to sell as KS has high selling value in market. EFB was composted into organic fertilizer to use in oil palm plantation field nearby currently. Biomass samples, such as EFB, MF, KS and Palm Oil Mill Effluent (POME) were collected on-site. Calorific value and elemental content of carbon, oxygen, hydrogen and nitrogen of solid biomass residue were analyzed by Bomb calorific value analysis (CAL2K ECO Bomb Calorimeter) and Elemental Analyzer (Carlo Erba 1108 Elemental Analyser) respectively.

Generally, for every tonnes of FFB processed, 0.7 tonnes of POME was generated in the selected mill. Ponding system consisting several ponds was used to reduce the high value of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of POME before discharge. However, no methane capture was conducted through ponding system at present due to the large pond size and high capital cost to install methane-capturing roof. As about 11.67kg/s of POME was generated in the mill, it is necessary to characterize the biomethane potential (BMP) of POME through anaerobic digestion to determine its methane production via methanogen. The main testing procedures was performed based on ISO 11734, ASTME 2170-2001 (2008) using Anaerobic Digestion facility.

2.3 Assumptions and Simulations

ECLIPSE software was used as a tool to simulate Combine Heat and Power (CHP) system and biomass power plant of the selected palm oil mill. ECLIPSE is stands for European Coal Liquefaction Process Simulation and Evaluation, which was developed within the Energy Research Centre (UU) in 1992 and copyrighted by University of Ulster. It uses generic chemical engineering equations and formulae, containing all of the program modules necessary to complete step-by-step technical, environmental and economic evaluations of chemical and allied process, as shown in Fig. 2 [28]. According to the modelling of the CHP system and the definition of the parameters, simulation on the working process was proceeded within ECLIPSE. Results of elemental analysis, calorific value analysis and biomethane potential analysis were gathered and input into ‘Compound Data’.

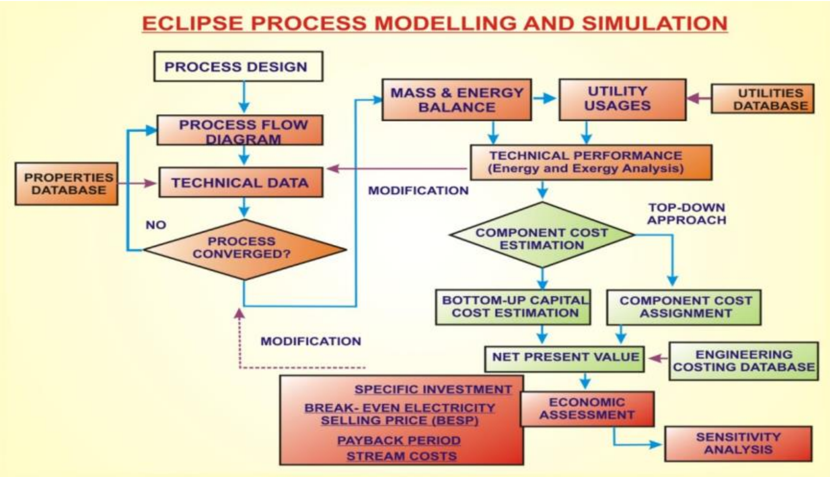

Fig. 2. Schematic diagram of ECLIPSE process modelling and simulation [28]

The biomass boiler, water tubes within the boiler and steam turbine generator were represented by ‘Chemical reaction’ module, ‘Heat Exchanger’ module, and ‘Gas/Liquid Expansion’ module respectively. Mesocarp fibre and kernel shell were mixed together with air before enter the boiler, i.e. the combustion chamber of the biomass boiler. Pumped water with 23 to 25 bar pressure was heated by the hot air produced by the ‘boiler’ and created steam. ‘Expander’ was high-pressure steam expanded through the turbine, and eventually generated electricity. Air mass flow rate for each fan on boiler was calculated by multiplied volumetric flow rate to respective air density. The fan outlet pressure can be calculated based on the static pressure provided. The air temperature for Induced draft (ID) fan was 320 ℃ while other fans were operated in atmospheric temperature, which was 30℃. The relative humidity of 70% was considered at 30℃ as well. The boiler combustion reaction was modelled into ECLIPSE by edit the ‘Yield Equation’. It was assumed that all dry biomasses were burned completely in adiabatic boiler and produces heat according to the calorific value analysis results. 1 percent of the total dry biomass weight was converted into char. The combustion reaction products were assumed to be carbon oxide, water, nitrogen oxide, and so on.

Two heat exchangers were set to present the water tube in ECLIPSE. The first heat exchanger was to heat the water to boiling point of 100℃ and second heat exchanger was used to produce saturated steam of 23 Bar and 221.8℃. It was presumed that each heat exchanger has pressure drops of 1 Bar. After the boiler and heat exchangers, the ash and char is removed by Ash Box. For back pressure steam turbine, an efficiency of 50% was assumed to convert energy from steam to rotational force with the steam pressure fixing at 3.5 Bar. The total efficiency of generator to switchbox was 84.6%. After mass and energy balance of the simulation was completed, the results was used in ‘Utility Usage’ analysis of ECLIPSE. The ‘Utility Usage’ analysed the overall utility used by the CHP and calculated amount of power generated from the steam turbine.

The simulation and optimization for effective utilization of biomass combined heat and power have been conducted in modifications of three different combinations of the biomass wastes: EFB and Shell as fuel for power generation, MF co-firing with Biogas, and power generation using KS, EFB and Biogas with preheaters.

3 Results and discussion

3.1 Simulation of CHP with EFB and KS as fuel for power generation

The testing results of calorific value analysis and elemental analysis of biomass wastes collected from the selected palm oil mill are shown in Table 1. It is found that the test data basically consistent with the literature [4-5, 10-11], the slightly difference in data may be because of specific regional environment.

Table 1 Results of calorific value analysis and elemental analysis of biomass wastes in the selected palm oil mill

Biomass waste	calorific value (MJ/Kg)	Element content (%)			
		C	H	N	O
EFB	18.54	44.09	6.18	1.62	48.11
MF	18.12	45.19	6.62	1.44	46.75
KS	18.98	47.64	6.57	1.08	44.71

The balance of Mass and Energy of CHP in selected palm oil mill was proceeded first using above results and other data under ECLIPSE. The mass and energy balance of CHP of existing palm oil mill is shown in Fig. 3. Total 3.115Kg/s of MF and 0.624 Kg/s of KS was used as biomass boiler fuel to generate electricity and steam for palm oil production process. The results obtained from ECLIPSE reveal that the simulation are successful and output data mainly match with the data provided from the palm oil mill. Then the simulation of CHP with EFB (replacing of MF) and KS as fuel for power generation has been studied using the same type of biomass boiler. The air flowrate for fans are not changed as the weight of EFB added into boiler is almost similar to Fibre. A new water pump and a steam condensing turbine have been introduced to match condition of required steam at 45Bar and 450 ℃. A total of 4.0876kg/s of EFB with 0.7488kg/s of KS are used as boiler fuel. Although the KS used in this case study is a bit more than the amount used actually (0.624 Kg/s of KS), it proves that the EFB can be used as a new biomass fuel, which is not used before for the CHP system. The overall air flow rate is increase from 31.92kg/s to 37.5kg/s as the combustion of EFB and more KS required more oxygen. An increment of 5.6kg/s of air in order to meet the same excess air ratio of 2.35. The amount of water circulating in the water tubes is tested to be 11.5kg/s.

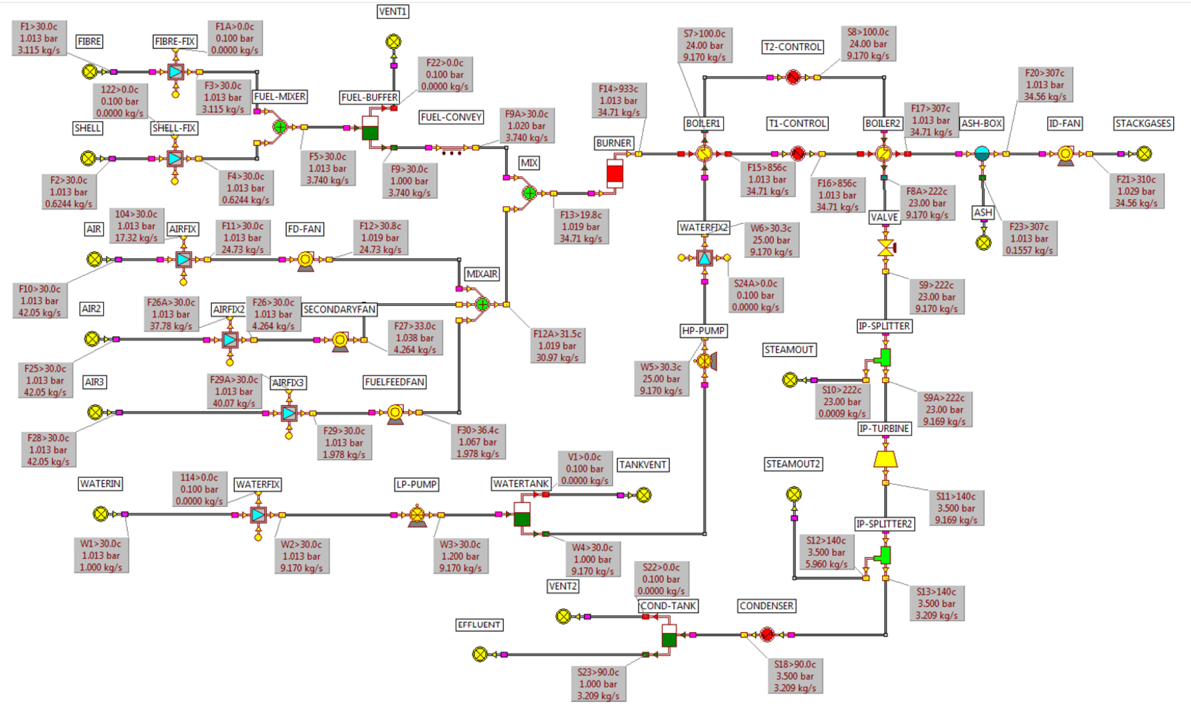

Fig. 3. Mass and Energy balance of CHP of chosen palm oil mill

The results from ECLIPSE shows that, when using EFB and KS (Kernel Shell) as fuel to the CHP system for power and heat (steam) generation, the CHP can produce not only enough electricity and steam for the production process, but also some extra electricity which can be sold to the national power grid. The results from ECLIPSE shows that the net electrical power generated from this simulation is 2.2MW, and 16.1GWh annually, for 4400 hours of operating hours per year, which is far more than the actual need for electricity of the mill (1.3MW). So, additionally, it could replace the old and unreliable diesel plants, reduce the dependency on fossil fuel, and could potentially relieve power shortage issue in the area.

3.2 Simulation of CHP with MF co-firing with biogas as fuel

Similar power plant in additional of co-firing with biogas is also demonstrated. This simulation used biogas produced from POME through anaerobic digestion to replace KS, as the prepared biogas mainly contains methane, which has high energy content after combustion. The KS saved, which is of high selling price in market, can be sold to get extra revenues for the Mill. The utilization of POME to produce biogas from anaerobic digestion will also benefit the environment. This is because the POME in the open pools can produce large amount of methane and release it to the atmosphere. Methane is recognized as a second largest greenhouse emission after carbon dioxide.

It is assumed that the anaerobic digester has hydraulic retention time of 30 days, the amount of methane produced from the assay must deducted from the blank value. Based on the experimental results as shown in Fig. 4, 500ml of methane is produced from the sample assay vessel and 280ml of methane is produced from the blanks. Therefore, a total of 220ml of methane is produced from 1 gram of volatile solid of POME. According to calculation, 6.19m^3 of methane is produced from one tonnes of POME. The total amount of POME produced from the mill is 0.7tonnes of POME from per ton of FFB. Therefore, with 800 and 184800 tonnes of FFB processed daily and annually, the weight of methane produced daily and annually is 2262.87 kg and 746745.75kg respectively. It is equivalent to 4.04 kg of methane per tonnes of POME, which is lower than most studies [29]. Carbon dioxide is produced along with methane during anaerobic digestion. The content in weight concentration of total biogas is assumed as 62.5% of CH_4, 37.2% of CO_2, and 0.3% of H_2S.

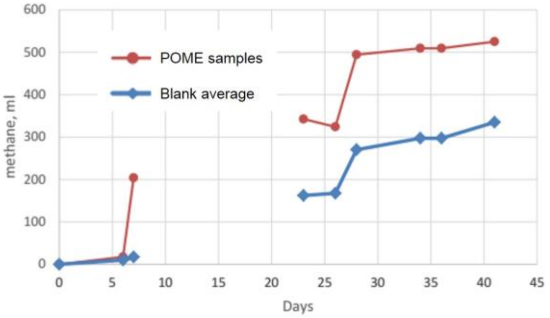

Fig. 4. Biomethane Potential of POME over 41 days

The MS and Biogas is added to the boiler at the flow rate of 3.115 kg/s and 0.07543kg/s respectively. Since amount of fuel is reduced, the amount of oxygen required is also reduced. Excess air would reduce the thermal efficiency of the heat exchanger or the water tubes due to lower thermal gradient and energy is wasted in fans compressor. The overall air flow rate is reduced from 31.92kg/s to 25.54kg/s whilst keeping the same excess air ratio of 2.36 as compare to simulation based on existing mill.

Simulation results show 1300.21 kW of power is produced from the steam turbine. In view of generator and power regulation efficiencies, the power at busbar is 1099.98kW, lower than 1.3MW, and it is insufficient to provide energy for the mill. Further improvement is made by introducing pre-heating the inlet water using vent gas after ash-box. Water is preheated to 100℃ at water pressure of 25bar. The steam produced after boiler has a temperature of 221.8℃ at 23Bar. According to the calculation in

Utility of ECLIPSE, power output was 1308.36kW and could meet the electricity demand. The improved simulation of MF co-firing with biogas with installation of water preheater shows replacing KS by Biogas is feasible as long as preheater is installed. 9890.5 tonnes of KS with high market value would be saved per year once biogas replacement is made.

3.3 Simulation of power generation using KS, EFB and Biogas with preheaters

This simulation used KS, EFB and Biogas as fuel. The total weight of KS, EFB and Biogas available from palm oil processing plant are 0.74 Kg/s, 4.0876 kg/s and 0.04714kg/s respectively. Air is preheated using flue gas after ash box. Biogas is co-firing with the biomass and is inserted into boiler via forced draft fan. In order to keep the same excess air ratio to 2.35, the air flow rate is altered to 21.74kg/s. the air inlet is designed to preheat to 140℃ from the tail gas after boiler. The total operating hours for this simulation is 7920 hours per year because the power plant is required to have availability of at least 90%.

The flow rate is fixed at 6.9 kg/s in order to produce steam of 450°C at 45Bar. The results show that the net power produced from this power plant is 2.4MW and 17.4 GWh of electricity annually is produced over a year. It could potentially cover the electricity for oil extraction process and the remainder, which is higher than the first case of ‘EFB and KS’ as fuel (2.2MW, and 16.1 GWh annually), could provide to the grid. It is calculated that, if all 117 palm oil mill in Sabah install the same type of biomass power plant, nearly 2000 GWh of electricity generated annually. This amount of electricity is 34% of the total electricity produced in the area in 2012. This will greatly reduce the carbon emissions from the electrical power generation sector in Malaysia and help the country to realize its commitment to cut carbon emissions to mitigate the global warming trend and climate change. It will also benefit the palm oil mills when/if mills are eligible for selling electricity to the grid. The payback time will be less if they are also given a feed-in-tariff for the electricity generated from renewable biomass wastes during the production process of palm oil.

Conclusion

A feasibility study of optimization and modification of palm oil biomass combined heat and power plant were conducted in a palm oil mill in Sabah, Malaysia. Biomass wastes were collected on site and analyzed in laboratory to determine their calorific value, chemical composition and biomethane potential. Simulation of the Combined Heat and Power plant were modelled using ECLIPSE software. The results show that the power plant generates 2.2 MW power when fueled with EFB and KS. 16.1 GWh of electricity can be potentially produced per year. Another simulation of feasibility studies on replacing KS by Biogas as fuel for existing CHP system. The results from the simulation reveal that Biogas is potentially capable to replace KS as fuel with preheating flue gas, which generated 1.3 MW power. The third simulation using EFB, KS and biogas show that the net power produced from this power plant is 2.4MW, and 17.4GWh annually. The simulations of power generation from palm oil biomass indicate it has great potential to provide electricity to the grid. This will help the country to reduce the carbon emissions greatly from the electrical power generation sector and realize its commitment to cut carbon emissions.

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