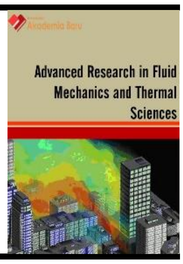
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Utilization of Oil Palm Biomass as a Renewable and Sustainable Energy Source in Aceh Province

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ARTICLE INFO

Article history:
Received 24 December 2019
Received in revised form 15 February 2020
Accepted 17 February 2020
Available online 18 March 2020

ABSTRACT

Oil palm production can convert and produce biomass waste, which has high energy value. Oil palm biomass (OPB) that can be discarded includes empty fruit bunches, palm oil leaves, stems, palm kernel shells and mesocarp fibres. Palm oil mills can produce a variety of products, one of which is renewable and sustainable energy, especially for power plant generators. This research concentrated on biomass-based cogeneration plant modelling and simulation. The objective of this article was to develop unit processes and configurations, simulate and optimize the cogeneration process in Aspen Plus simulator using biomass such as EFB, PKS and OPF as fuel. Moreover, this simulation is carried out to find the constant value of the biomass flow rate and the airflow rate and to do some variations with different variables and scenarios. Simulation results have shown results that are appropriate for the biomass flow rate of 5 kg/s with an airflow rate of 58.5 kg/s. Recycle LP-Stream without utilizing stream exhaust which is simulated that the recycle value that can be charged is 20%. While recycle using the exhaust value that can be installed is 80%. The more recycles that are made with various variations show better results. Overall simulation results in this paper have reached a constant value.

Keywords:
Oil palm; Aspen Plus; Simulation; Cogeneration; Modelling

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1. Introduction

Indonesia is the second country after Malaysia as the largest producer of palm oil in Southeast Asia even in the world. Production from oil palm in Indonesia, especially solid waste (biomass) every year can produce around 4.4 million tons or 32,654 MWe. While oil palm products in Aceh Province alone can produce around 116.5 thousand tons every year. These palm oil biomasses such as oil palm leaves (OPL), oil palm trunks (OPT), empty fruit bunch (EFB), palm kernel shells (PKS), mesocarp fibers (MF), and oil palm stones (OPS). Research on the status of biomass found in Indonesia and especially in the Langsa area, Aceh Indonesia been studied by [1]. Energy sources for electricity generation can generated from the use of biomass [2-4]. Similar studies regarding the use of biomass as fuel have also been studied [5-9]. Energy or thermal energy production that can directly generated from biomass utilization. Cogeneration and polygeneration energy systems have been analysed [10-13].

In addition, most biomass products come from palm oil and can categorized as bio-oil [14-18]. Besides bio-oil, biomass can also produce as biofuel [19-23]. To clean and cool the syngas from the biomass process results have also been studied [24-26]. While the production of biomass to produce fuel in the past few have increasingly been studied [27-31]. The effect of pre-treatment by leaching dilute nitric acid to remove inorganic materials and increasing bio-oil production using oil palm EFB has been investigated [32]. The results showed that dilute nitric acid pre-treatment at EFB increased total liquid 63.9% from 52.2% and reduced char by 41.9% from 39.9% compared to original EFB. Empty oil palm bunches have the potential to increase the economy because they can produce multi-products that range from energy, chemicals, and other energy materials [33]. In this case, biomass supply chain modelling can function as a supporter who can provide economic indications for future investments.

Renewable energy sources in Indonesia are currently classified as very rich which can be utilized. This abundant renewable energy is one of them is biomass from oil palm which can be processed into heat energy or as a power plant. However, until now the Indonesian state in general continues to face a crisis with energy problems. Many of the renewable energy currently available has not been able to use as energy. The installed power plant capacity until 2018 is around 1,717.1 MWe from a total of 32,654 MWe of resources or 1,626 MW off grids and 91.1 MW on grids. This is as the result of the analysis reported in the Indonesia Energy Outlook [34]. Indonesia's potential for new and renewable energy (NRE) is quite large, with a variety of different types of energy. However, the potential for EBT has not developed optimally due to various obstacles in its implementation. Constraints that hamper such as high investment costs, relatively low technological efficiency, geographical location, and social factors of the community as users of primary energy. Based on a national study the potential of biomass as a power plant in Indonesia reaches 50 GW. The government is targeting the use of plants from biomass power as small and scattered/distributed plants as well as for medium scale. While in Aceh alone the presence of biomass can only find in palm oil mills (POM). The use of biomass as a power plant and as evaporation in Aceh is still very limited (only self-needs). While for independent power plants (IPP), very little shown. The capacity of electricity and heat generation installed in POM is 65 MW and 10 MW from IPP to the surrounding network. The diminishing fossil energy reserves in Indonesia and generally in the world today have caused energy problems in remote and border areas. In addition, investment in development towards renewable energy requires high costs. However, the level of use, the probability and returns are relatively long and cannot ascertained in the near future. So that investors have not been interested in developing renewable and sustainable energy.

This research concentrated on biomass-based cogeneration plant modelling and optimization. The objective this article was to model, simulation and optimize the cogeneration process in Aspen

Plus simulator using biomass such as EFB, PKS and OPF as fuel. Moreover, this simulation is carried out to find the constant value of the biomass flow rate and the airflow rate and to do some variations with different variables and scenarios.

2. Material and Methodology

The materials used in this analysis are empty fruit bunch (EFB), which can be found in oil palm mills abundantly. The material in this study is as shown in Figure 1. Proximate data of EFB consist of moisture 9.38%, ash 5.38%, volatile matter 68.47%, and fixed carbon 16.77%; then calorific value 4,469 cal/g. Thereafter, ultimate data comprise of carbon 46.5%, hydrogen 7.13%, nitrogen 0.89%, total sulphur 0.21% and oxygen 39.89% (all the data are in the air dry basis). This analysis based on the availability of materials throughout the Aceh Province and their use as renewable and sustainable energy for electricity.

Analysis with the Aspen Plus V9 Software done to facilitate the actual application or experimental processing to reduce costly damage to the engine. Biomass processing machines and combustor are currently installed at the Faculty of Engineering Laboratory, Universitas Abulyatama in collaboration with Laboratory of Energy Resources, Department of Chemical Engineering at Universitas Syiah Kuala.

Fig. 1. Empty fruit bunch

The biomass-based cogeneration plant model was created using Aspen Plus, where the references are taken in this article as well as articles that have been published by [35]. While the elements involved in this work are graphite carbon, hydrogen, nitrogen, oxygen, sulfur, water, carbon dioxide, nitric oxide and nitrogen dioxide. Table 5 showed the working circumstances for the inlet streams. Simulations made using the Aspen Plus V9 Software in this paper simulate five different scenarios (such as Scenario-1 without any recycle and heat recovery; Scenario-2 with LP-steam recycle; Scenario-3 with LP-steam recycle and utilization of exhaust stream or exhaust gas; Scenario-4 with LP-steam and condensate recycles; Scenario-5 with LP-steam and condensate recycles and utilization of exhaust stream) are shown in Figure 2-5. The scenario is simulated in this paper as explained below.

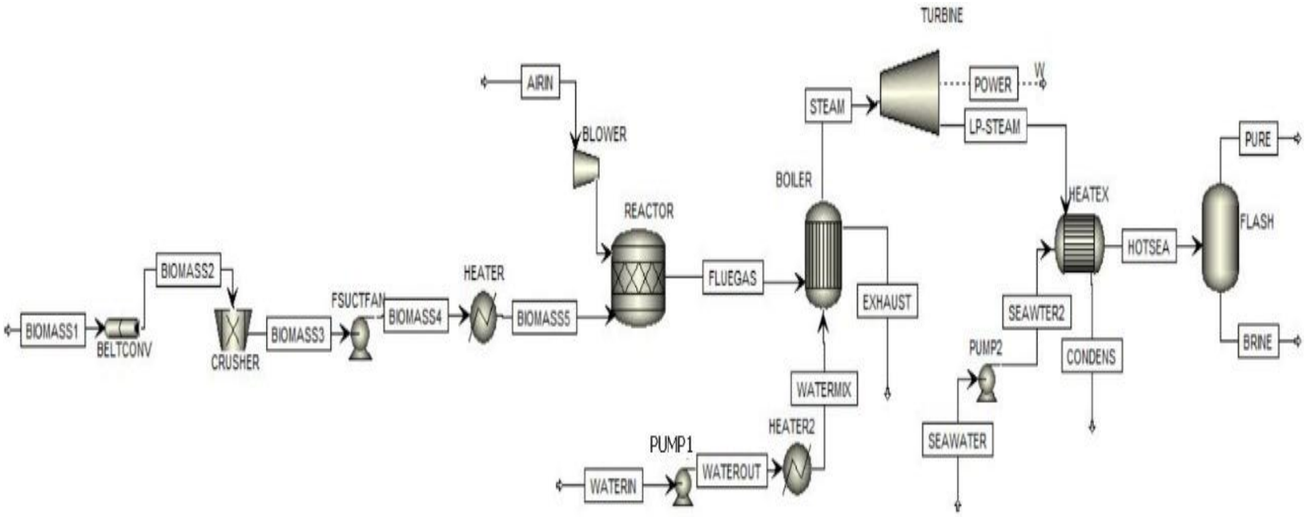

Fig. 2. Configuration of biomass cogeneration in Scenario-1

Cogeneration biomass in Scenario-1 designed without recycle and energy recovery is made to determine the suitable of air to fuel ratio (AFR) as shown in Figure 2. The final simulation for this scenario is conducted at air flow rate 58.5 kg/s and biomass flow rate 5 kg/s for boiler feed water flow of 41,400 kg/h (11.5 kg/s). At these conditions, the AFR is 11.7. In this simulation the temperature recorded for Steam Turbine is 787.78°C and LP-steam is 564.46°C with pressure of 45 and 3.5 bars, respectively. In addition, other conditions involved in supporting this simulation show in Table 1. The results of this simulation are more detailed as described in Figure 6 and 7. Brief explanation for the first scenario: EFB size is reduced by using a crusher, then the fan is functioning to suppress the mashed biomass to the heater. After that, the heated biomass then pulled into the reactor (combustor) for the combustion process to produce the heat that is carried by flue gas into the boiler. The boiler functions to generate steam. Steam coming out of the boiler is used to drive the turbine to produce power. LP-steam exit the turbine is flowed to Heat Exchanger (HE) to heat the flash feed seawater. Inside the flash, pure water and salt are separated.

Table 1
Simulation conditions for Scenario-1

Description	Units	Simulation of Biomass Flow Rate		Simulation of Air Flow Rate	
		STEAM	LP-STEAM	STEAM	LP-STEAM
From		BOILER	TURBINE	BOILER	TURBINE
To		TURBINE	HEATEX	TURBINE	HEATEX
Temperature	C	787.78	564.46	787.78	564.462
Pressure	bar	45	3.5	45	3.5
Molar Enthalpy	cal/mol	-51065.33	-53126.22	-51065.3	-53126.2
Mass Enthalpy	cal/gm	-2834.56	-2948.95	-2834.56	-2948.95
Molar Entropy	cal/mol-K	-7.17	-4.31	-7.16831	-4.31366
Mass Entropy	cal/gm-K	-0.40	-0.24	-0.3979	-0.23944
Molar Density	mol/cc	0.00	0.00	0.000515	5.04E-05
Mass Density	gm/cc	0.01	0.00	0.00928	0.000907
Enthalpy Flow	cal/sec	32597398.67	33912961.69	-3.3E+07	-3.4E+07
Mole Flows	kmol/h	2298.05	2298.05	2298.049	2298.049
Mass Flows	kg/h	41400	41400	41400	41400
Volume Flow	l/min	74353.27914	760524.8816	74353.28	760524.9

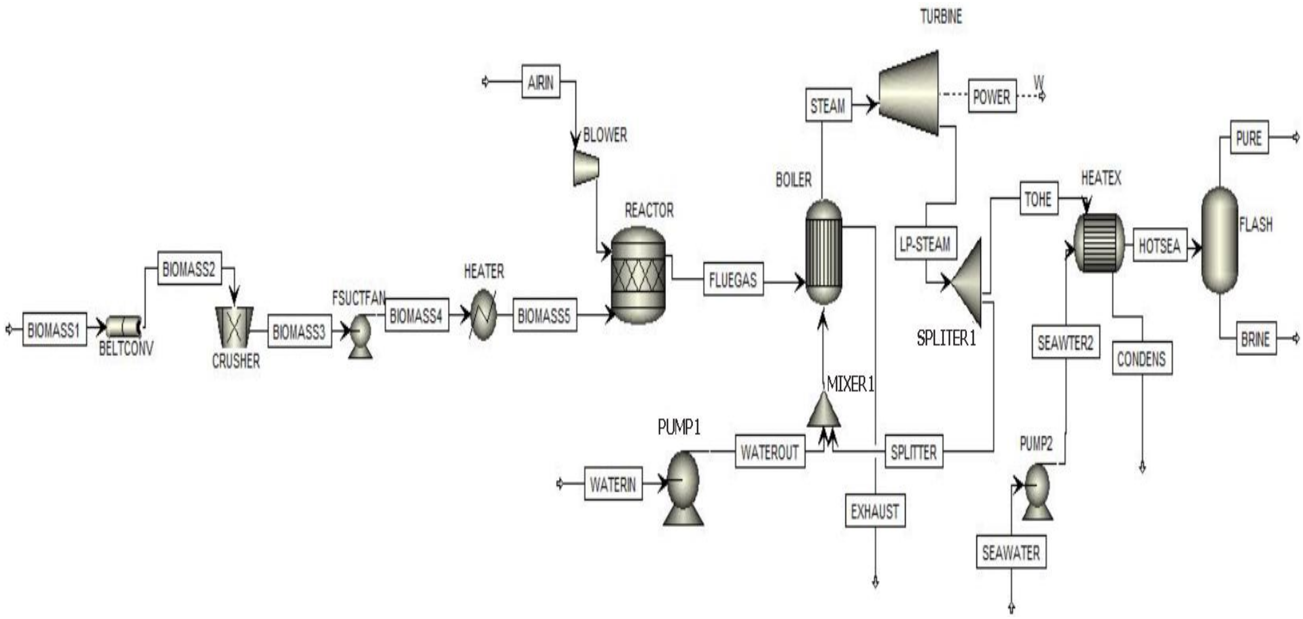

Fig. 3. Configuration of biomass cogeneration in Scenario-2

The cogeneration biomass design in the Scenario-2 is simulation for cogeneration of biomass with a recycle LP-steam as shown in Figure 3. However, in this scenario it does not utilize the exhaust stream. Boiler conditions are 799^{o}C and 45 bar with AFR similar to Scenario-1. In addition, other related conditions in more detail are listed in Table 2. The design in the second scenario of LP-steam is divided into two streams, one flow to heat the seawater and a portion of the flow is recycled back into the boiler. As expected, boiler feed water can be enhanced a little (from 41,400 to 46,000 kg/h) in order to consume energy from LP-steam recycling.

Table 2
Simulation conditions for Scenario-2

Description	Units	STEAM	LP-STEAM
From		BOILER	TURBINE
To		TURBINE	SPLITTER
Temperature	C	799	574.08
Pressure	bar	45	3.5
Molar Enthalpy	cal/mol	-50950.6	-53035.7
Mass Enthalpy	cal/gm	-2828.19	-2943.93
Molar Entropy	cal/mol-K	-7.06076	-4.20626
Mass Entropy	cal/gm-K	-0.39193	-0.23348
Molar Density	mol/cc	0.000509	4.98E-05
Mass Density	gm/cc	0.009178	0.000897
Enthalpy Flow	cal/sec	-3.6E+07	-3.8E+07
Mole Flows	kmol/h	2553.388	2553.388
Mass Flows	kg/h	46000	46000
Volume Flow	l/min	83530.22	854808.2

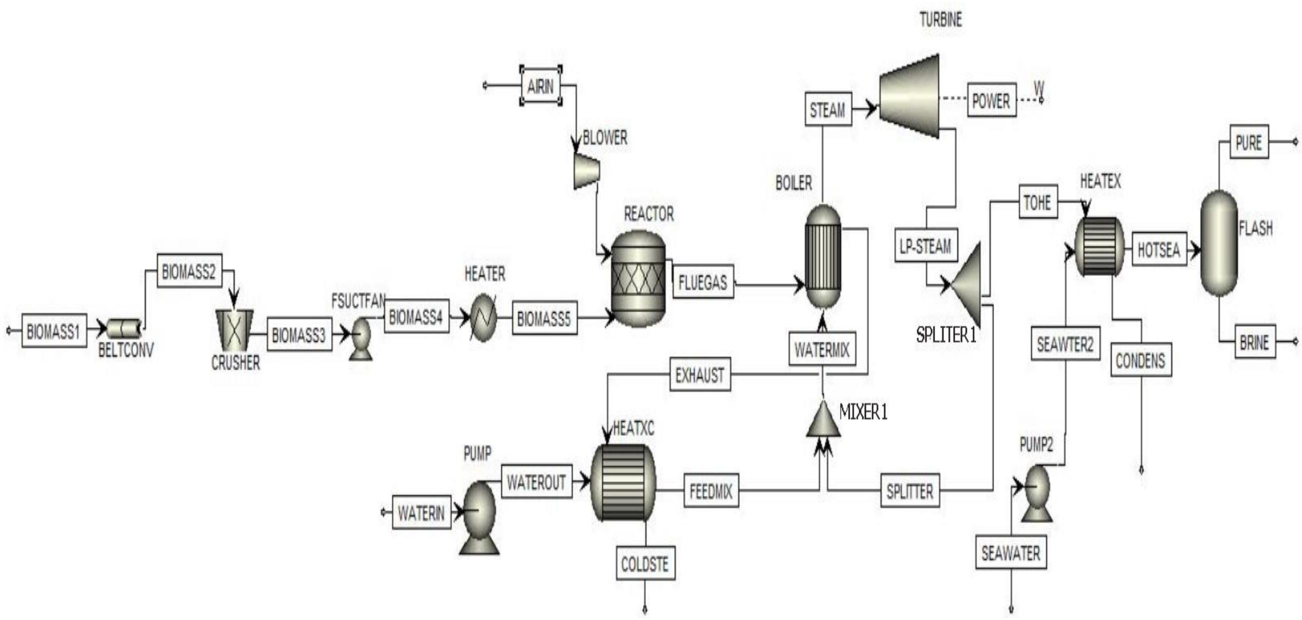

Fig. 4. Configuration of biomass cogeneration in Scenario-3

Biomass for cogeneration with the use of exhaust stream is also simulated in this study. The design of the exhaust stream utilization is simulated as shown in Figure 4. For the operating conditions used in this scenario such as Boiler temperature and pressure are 257°C and 45 bar, respectively. The AFR is same to Scenario-1 and -2. Besides, several conditions can support this simulation as shown in Table 3. The third scenario is similar to scenario two but in this scenario, the exhaust flow coming out of the boiler is used to heat the boiler feed flow before it is combined with LP-steam which is recycled from the turbine.

Table 3
Simulation cconditions for Scenario-3

Description	Units	STEAM	LP-STEAM
From		BOILER	TURBINE
To		TURBINE	SPLITTER
Temperature	C	257	139
Pressure	bar	45	3.5
Molar Enthalpy	cal/mol	-56378.2	-57372.6
Mass Enthalpy	cal/gm	-3129.46	-3184.67
Molar Entropy	cal/mol-K	-14.12	-11.6925
Mass Entropy	cal/gm-K	-0.78378	-0.64903
Molar Density	mol/cc	0.001221	0.000111
Mass Density	gm/cc	0.021989	0.001994
Enthalpy Flow	cal/sec	-4E+07	-4.1E+07
Mole Flows	kmol/h	2553.388	2553.388
Mass Flows	kg/h	46000	46000
Volume Flow	l/min	34865.63	384410.9

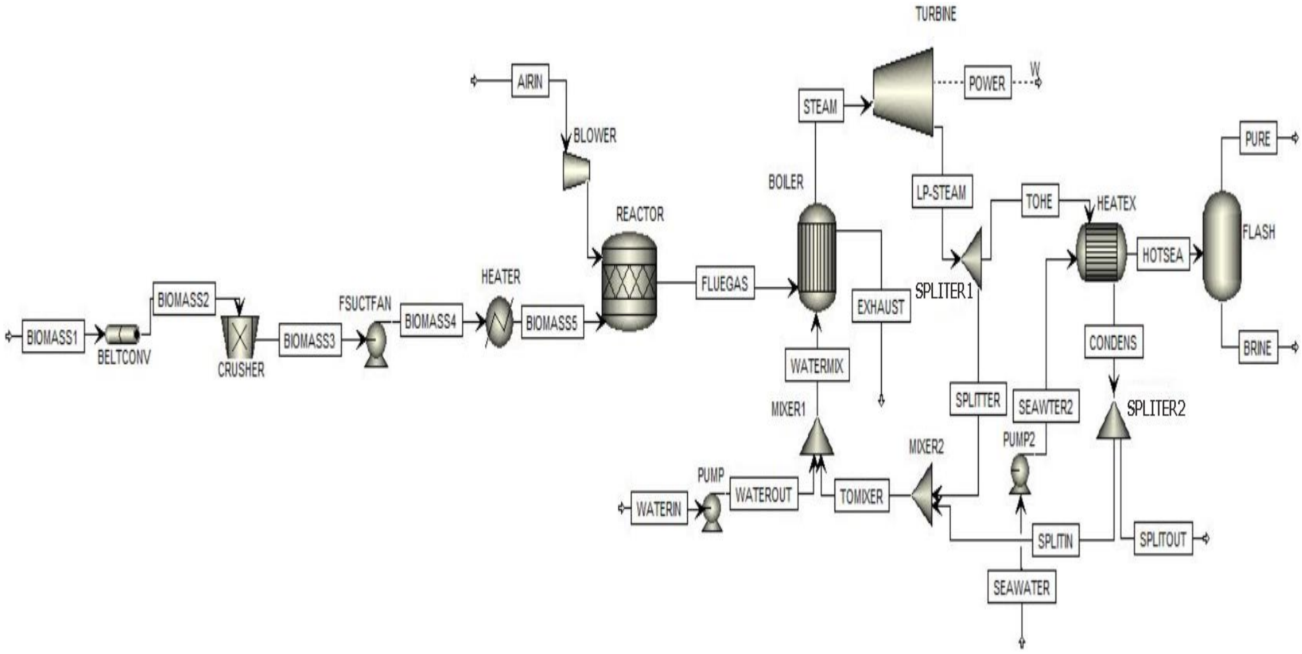

Fig. 5. Configuration of biomass cogeneration in Scenario-4

The Scenario-4 carried out in this simulation is a cogeneration of biomass with a recycle of LP-steam and condensate as shown in Figure 5. At this stage, only pressure of Steam Boiler and LP-steam conditions are similar to the previous ones. Others simulation conditions are quite different. The simulations in Scenario-4 and -5 are run on the AFR 6.91 (using an airflow rate of 121 kg/s with a biomass flow rate of 17.5 kg/s) and Boiler feed water flow 230,000 kg/h. However, the difference lies in the recycle condensate of HE seawater without and with utilizing the exhaust gas heat. The Scenario-5 is performed in the configuration with using the energy recovery scheme. Simplily, Scenario-5 is the combination of Scenario-3 and Scenario-4. Table 4 is the simulation conditions used for the simulation for Scenario-4.

Table 4
Simulation conditions for Scenario-4 and -5

Description	Units	Scenario-4		Scenario-5	
		STEAM	LP-STEAM	STEAM	LP-STEAM
From		BOILER	TURBINE	BOILER	TURBINE
To		TURBINE	SPLITER1	TURBINE	SPLITER1
Temperature	C	799	574.18	799	574.18
Pressure	bar	45	3.5	45	3.5
Molar Enthalpy	cal/mol	-50949.5	-53034.8	-50949.5	-53034.8
Mass Enthalpy	cal/gm	-2828.13	-2943.88	-2828.13	-2943.88
Molar Entropy	cal/mol-K	-7.0597	-4.2052	-7.0597	-4.2052
Mass Entropy	cal/gm-K	-0.39187	-0.23342	-0.39187	-0.23342
Molar Density	mol/cc	0.000509	4.98E-05	0.000509	4.98E-05
Mass Density	gm/cc	0.009177	0.000897	0.009177	0.000897
Enthalpy Flow	cal/sec	-1.8E+08	-1.9E+08	-1.8E+08	-1.9E+08
Mole Flows	kmol/h	12766.94	12766.94	12766.94	12766.94
Mass Flows	kg/h	230000	230000	230000	230000
Volume Flow	l/min	417696.5	4274526	417696.5	4274526

Table 5
Operating conditions for the inlet streams

Stream	Biomass	Air	Boiler Feed Water
Operation	Temperature: 25°C Pressure: 1 bar Mass flowrate: 5 kg/s Valid phases: Vapour-liquid	Temperature: 25°C Pressure: 1 bar Mass flowrate: 37.5 kg/s Mole fraction: 0.79 (Nitrogen) and 0.21 (Oxygen) Valid phases: Vapour-liquid	Temperature: 25°C Pressure: 2 bar Mass flowrate: 11.5 kg/s Valid phases: Vapour-liquid Mole fraction: 1

First, the elements concerned were defined by using Peng Robinson state equation as a property method in the Aspen Plus properties chapter. The first system, two streams enter the boiler, with EFB as fuel and air for oxygen supply in combustion reactions. After passed the CRUSHER, EFB is entered a HEATER at 25°C and 1 bar before heating up to 250°C. EFB and air then joined in a reactor stoichiometric reactor (REACTOR). As its valid phases, the reactor operated with vapor-liquid at 787.78°C and 45 bar to produce a 45 bar superheated steam at 787.78°C. The oxidation reactions for feed such as carbon, hydrogen, sulphur, nitrogen and nitric oxide were mentions below.

$$C + O_2 \rightarrow CO_2 \tag{1}$$

$$2H_2 + O_2 \rightarrow 2H_2O \tag{2}$$

$$S + O_2 \rightarrow SO_2 \tag{3}$$

$$N_2 + 1/2O_2 \tag{4}$$

$$2NO + O_2 \rightarrow 2NO_2 \tag{5}$$

The combusted gas generated then reached a thermal exchanger (BOILER) representing a water tube boiler. The 45 bar outlet pressure was presumed in the pressure drop portion to generate a high-pressure stream. At the same time, a 25°C water inlet stream was pumped at a pressure of 45 bar and then connected to a heater (HEATER1) to heat to 98°C before joining the heat exchanger as its cold inlet. The exhaust gas was released from the thermal exchanger's warm outlet flow. Meanwhile, the thermal exchanger's cold outlet flow that was label as STEAM became a superheated steam that was then subjected for power generation to a backpressure steam turbine. It was presumed that the steam turbine (TURBINE) was isentropic. The steam turbine operated at 3.5 bar with an effectiveness of 50 per cent [35]. The energy produced was transmitters for energy distribution to the primary switch box while exhaust gas was sent for heating the Boiler feed water (in some cases). The data were analysed once the simulation converged and compared to the energy output of the published journal to validate the method established.

3. Results

The highest power generated from the simulation was 4.46 MW and the low vapour pressure of 3.5 bar exit from the turbine, the power significantly higher compared to previous studies i.e. 1.76 MW and 2.2 MW, respectively which were simulated on Aspen Plus and ECLIPSE [35,36]. These differences may be due to previous evaluations have not been optimized. Moreover, 4.46 MW of electricity generated from Aspen-Plus has exceeded the real electricity requirements for the 1.3 MW plant. Thus, when combustion biomass (such as EFB used as fuel), the plant can generate more than enough electricity and stream for the manufacturing method. It is possible to sell the extra electricity to the domestic power grid. Thus, renewable and environmentally friendly crops that use EFB in a single form, EFB in a pile and EFB fibre as fuel can replace the ancient and conventional fossil fuel crops. Furthermore, it is possible to reduce dependence and demand on fossil fuels and minimize environmental degradation.

The results of the analysis with Aspen Plus were carried out with five different scenarios. The results of all the simulated scenarios will be explained based on the sequence of simulations that have been made as described below. The simulation process in the first scenario is carried out to find the appropriate AFR value. Where appropriate results are obtained for the biomass of 5 kg/s with an airflow rate of 58.5 kg/s shown in Figures 6 and 7. The procedure is carried out on the trial and error at a fixed air flow rate so that the biomass flow rate can reach a constant value. Next, a simulation is carried out to find the air flow rate at above constant flow rate of biomass. Figures 6 and 7 show trial and error for biomass flow rate and air flow rate.

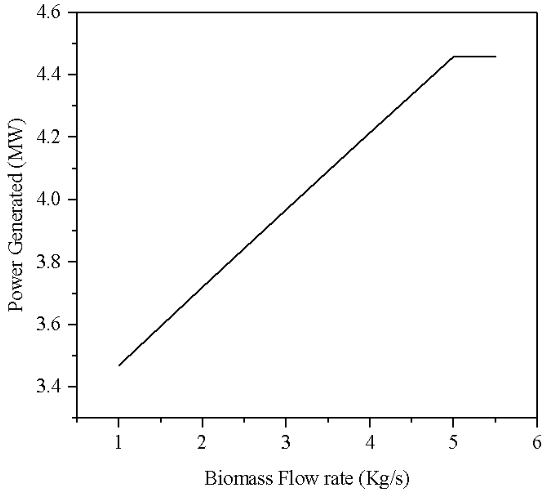

Fig. 6. Power at Various Biomass Flow Rate

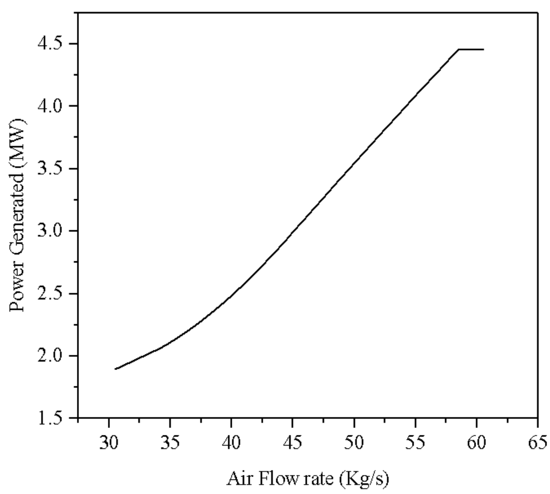

Fig. 7. Power at Various Air Flow Rate

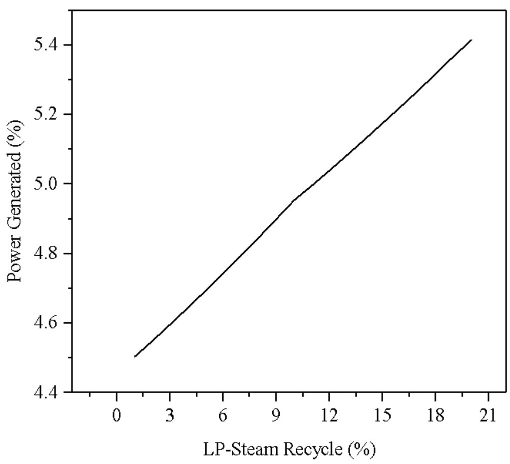

Fig. 8. LP-steam recycle with the utilization of exhaust stream

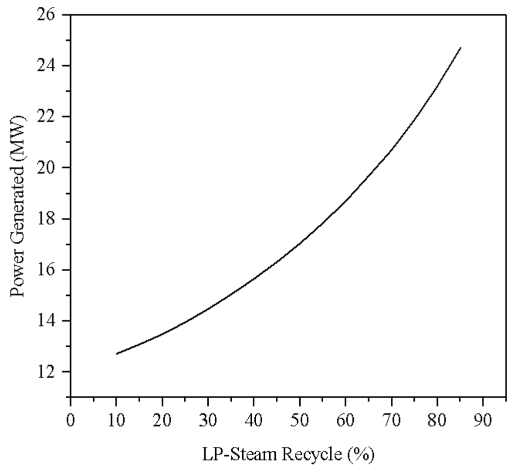

Fig. 9. LP-steam recycle without the utilization of exhaust stream

Figure 8 is the result of LP-steam simulation without heat recovery from the exhaust stream that is run in the Scenario-2. Where at this stage the process carried out using a flow rate biomass is 5 kg/s with an airflow rate of 58.5 kg/s. At this stage, it does not utilize exhaust so the maximum LP-steam can be recycled is 20%. While the simulation with recycling the LP-steam and use of the exhaust stream is shown in Figure 9. In the recycling with the use of exhaust stream the yield sharply increases can be recycled is 80%. For the biomass flow rate and the airflow rate used is 5 kg/s and 58.5 kg/s, respectively. The simulation in the two and three scenarios is the value of the results obtained in the first scenario. The values from Figures 8 and 9 for the use of exhaust stream and with the use of exhaust stream in LP-steam show a very significant trend for electrical energy.

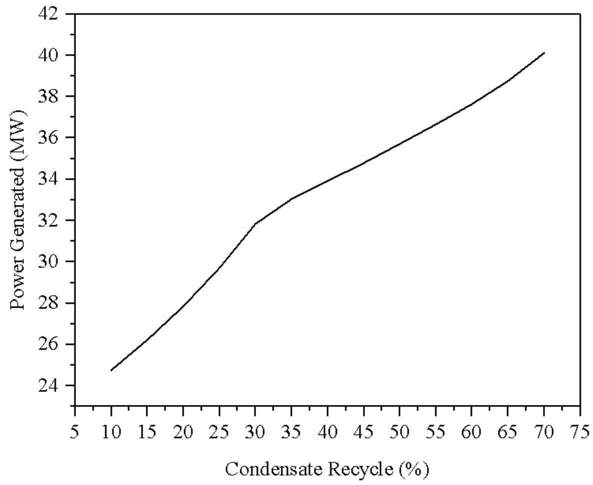

Fig. 10. Condensate recycle without the utilization of exhaust stream

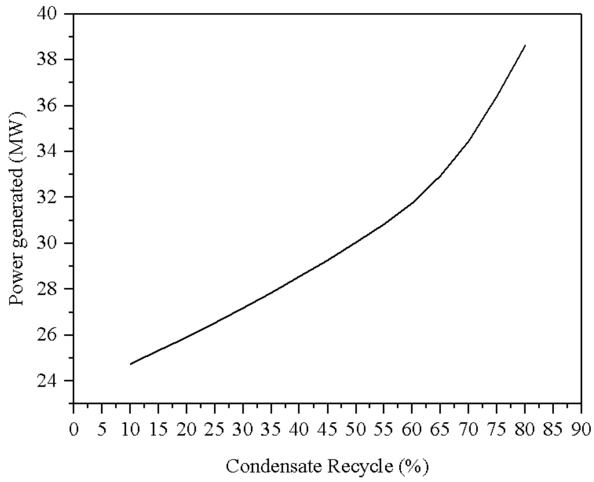

Fig. 11. Condensate recycle with the utilization of exhaust stream

Then the simulation is continued with Scenario-4 and Scenario-5 as shown in Figures 10 and 11. This simulation is carried out to find new or better AFR values than the previous values contained in Scenario-1 to Scenario-3. The simulation in Scenario-4 is run at a biomass flow rate of 17.5 kg/s with an airflow rate of 121 kg/s. In Scenario-4 it is run with a condensate recycle without utilizing the exhaust stream. The simulation results allowed in the allowed 4% recycle scenario are shown in Figure 10. While the recycle condensate with the utilization of exhaust stream has increased to 80% shown in Figure 11. However, the increase that occurred was not significant (10%) compared to the Scenario-2 and Scenario-3 are (60%).

4. Conclusions

The results obtained in the article are the results of simulations with Aspen Plus V.9 Software by utilizing biomass in producing energy and also fresh water. This simulation was made with five different scenarios so that several conclusions can be drawn as follows:

i. The simulation results carried out showed the appropriate results, where the biomass flow rate of 5 kg/s with an airflow rate of 58.5 kg/s. These results have reached a constant condition of the biomass flow rate.
ii. The LP-steam recycle without utilizing exhaust stream which is simulated that the part of recycling that can be loaded is 20%.
iii. The biomass flow rate of 5 kg/s with an airflow rate of 58.5 kg/s which is simulated with recycling that is utilized from the exhaust that the recycle value that can be filled is 80%.
iv. The Scenario-4 and -5 cannot be run with a biomass flow rate of 5 kg/s and an airflow rate of 58.5 kg/s. Therefore, at this stage the more appropriate flows searching was performed so that the biomass flow rate was obtained at 17.5 kg/s with an airflow rate of 121 kg/s. Thus, the recycle value was reached up to 80%.

The results obtained from this simulation have reached a constant point for the biomass and the air flow rates. However, several different variations need to be made for future work. Besides, the simulation results in this paper will be used as references in the experiments being carried out and will be compared in our next work.

Acknowledgement
The KEMENRISTEK DIKTI and Universitas Syiah Kuala, Research institutions and community service with the contract number of (20/UN11.2/PP/PNBP/SP3/2019), supported this research.

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