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Coconut Waste Pyrolysis Simulation Using Aspen Plus Software

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ABSTRACT

Currently, in the world are trying to substitute fossil energy for renewable energy. One of the renewable energy is biomass energy. Biomass is a renewable natural resource derived from biological nature. Biomass from palm shells has been successfully used by the Tembilahan PLTU as an effort to substitute coal. The results of technical evaluation and monitoring show operating parameters within normal limits. Palm shells are known to have a lower sulfur content than coal so that the emissions produced are less than coal. When viewed from the characteristics based on the analysis of proximate, ultimate and calorific value, it shows that the characteristics of biomass from coconut waste, especially coconut shells, are not significantly different from biomass from palm shells. This means that coconut shells can be considered as a renewable energy source. To improve the quality of the calorific value of biomass, a pyrolysis process is carried out to produce bio-charcoal. Modeling using Aspen Plus software has a difference average of less than 6%. Simulation results of coconut shell pyrolysis with maximum yield of bio-charcoal occurring at an operating temperature of 600°C which produces a total of 30.35% bio-charcoal, a calorific value (LHV) of 33.03 MJ/kg, and an ash content of 18.99%. While the simulation results of coconut shell pyrolysis with maximum syngas yield occurred at an operating temperature of 800°C which produced 82.43% syngas, high H_2 49.67% and low CO_2 2.90%.

Keywords: Bio-charcoal, Syngasbiomass, Coconut shell, Pyrolysis, Renewable energy

ABSTRAK

Saat ini negara-negara di seluruh dunia sedang berupaya untuk melakukan subtitusi energi fosil menuju ke energi terbarukan. Energi terbarukan salah satu diantaranya yaitu energi biomassa. Biomassa merupakan sumber daya alam terbarukan yang berasal dari alam hayati. Biomassa dari cangkang kelapa sawit berhasil digunakan PLTU Tembilahan sebagai upaya subtitusi batu bara. Hasil evaluasi dan pemantauan teknis menunjukkan parameter operasi dalam batas normal. Cangkang kelapa sawit diketahui memiliki kadar sulfur yang lebih rendah dari batu bara sehingga emisi yang dihasilkan lebih sedikit dibandingkan batu bara. Jika dilihat dari karakteristiknya berdasarkan analisis proksimat, ultimat dan nilai kalor menunjukkan bahwa karakteristik biomassa dari limbah kelapa khususnya tempurung kelapa tidak berbeda signifikan dengan biomassa dari cangkang kelapa sawit. Artinya bahwa tempurung kelapa dapat dipertimbangkan sebagai sumber energi terbarukan. Untuk meningkatkan kualitas nilai kalor biomassa maka dilakukan proses pirolisis untuk menghasilkan bio-arang. Pemodelan menggunakan perangkat lunak aspen plus memiliki rata-rata ketidaksesuaian kurang dari 6%. Hasil simulasi pirolisis tempurung kelapa dengan hasil bio-arang yang maksimum terjadi pada suhu operasi 600°C yang menghasilkan jumlah bio-arang 30.35%, nilai kalor (LHV) 33.03 MJ/kg, dan kadar abu 18.99%. Sedangkan hasil simulasi pirolisis tempurung kelapa dengan hasil syngas yang maksimum terjadi

pada suhu operasi 800°C yang menghasilkan jumlah syngas 82.43%, H_2 yang tinggi 49.67% dan CO_2 yang rendah 2.90%.

Kata kunci: Bio-arang, Syngas, Biomassa, Tempurung kelapa, Pirolisis, Energi terbarukan

INTRODUCTION

Renewable energy capacity in Indonesia is targeted at 23%(more than 400 MTOE) in 2025 and 31% in 2050, (more than 1000 MTOE). Renewable energy is targeted in Indonesia, especially by biomass, which is 26 GW by 2050 (National Energy Council, 2020). The United States already uses biomass about 3% of the country's energy demand, equivalent to about 3.2 million TJ/year (70 MTOE/year), in Europe 3.5% of its energy demand from biomass (about 40 MTOE/year), while some countries such as Finland, Sweden, and Austria generate 18%, 17%, and 13% of their total energy from biomass (Tursi, 2019). Biomass is a renewable natural resource derived from biological nature. The Tembilahan PLTU has successfully tested 100% of palm shell biomass as an effort to substitute coal. The results of technical evaluation and monitoring show that the operating parameters in normal limits and stable at 7 MW load (Nurhayati, 2022). Palm shells have a lower sulfur content than coal so that the emissions produced are also less than coal (Sugiyanto, 2021). Based on the analysis of proximate, ultimate and calorific value, it shows that the characteristics of coconut shell biomass are not significantly different from palm shells. This means that coconut shells can be considered as a renewable energy source. The difference can be seen in Table 1.

Table 1. The results of proximate, ultimate and calorific value analysis of coconut shell and palm shell

Parameter	Coconut Shell Najib & Darsopuspito (2012)	Palm Shell Sugiyanto (2021)
Moisture (wt. %)	6.51	12.21
Fix Carbon (wt. %)	17.11	18.38
Volatile Matter (wt. %)	68.82	68.67
Ash (wt. %)	7.56	0.74
Carbon (C) (wt. %)	47.89	48.01
Hydrogen (H) (wt. %)	6.09	5.51
Nitrogen (N) (wt. %)	0.22	0.18
Sulphur (S) (wt. %)	0.05	0.05
Oxygen (O) (wt. %)	45.75	33.30
LHV (MJ/kg)	20.89	19.00

From table 1 it can be seen that the parameters of fixed carbon and volatile matter in coconut shells and oil palm shells are not significantly different. Sulfur content in both samples is the same. These two parameters affect the calorific value based on equation (2). If based on the results of the analysis using a bomb calorimeter, the calorific value of coconut shells and palm shells is not significantly different. The difference is that the ash in the coconut shell is higher than that in the oil palm shell, but the moisture in the coconut shell is lower than that in the oil palm shell.

To improve the quality of the heating value of biomass, a pyrolysis process is carried out (Ridhuan et al., 2019). Pyrolysis is a chemical decomposition process using heating with little or no use of oxygen in combustion. Products that can be produced from the pyrolysis process are bio-charcoal, syngas and liquid smoke. The quality of the pyrolysis product makes it superior to other thermochemical conversion techniques. Pyrolysis products contain low sulfur and NOx gas so they are environmentally friendly (Novita et al., 2021). The pyrolysis process on a large scale has a more efficient production process cost (Wang et al., 2017). Pyrolysis of biomass can produce bio-charcoal products efficiently (Zhang et al., 2010). In the pyrolysis process of biomass, pyrolysis temperature has the greatest impact on the yield of bio-charcoal (Choi et al., 2012).

To find out bio-charcoal and syngas products from the results of the pyrolysis process without conducting experiments directly, it can be done by modeling using the Aspen Plus software with an error of less than 5% (Liu et al., 2022). The simulation results using Aspen Plus can be used because the response from the simulation results is close to the real pyrolysis results. Aspen Plus is a process modeling software used by industry to predict the performance of a process. In recent years, the application of Aspen Plus modeling software in process engineering has become a common practice because Aspen Plus can model processes in solid, liquid and vapor phases (AlNouss et al., 2018). Several recent research works have proven that Aspen Plus can be used to analyze pyrolysis studies to predict process yields (Elkhalifa et al., 2019). Ismail et al. conducted a pyrolysis study of waste tires using Aspen Plus (Ismail et al., 2017). The Aspen Plus model was successfully implemented to predict the production of pyrolysis products (AlNouss et al., 2021). Kabir et al. conducted simulations and experimental investigations on the pyrolysis of municipal green waste (Kabir et al., 2015). The simulation results using Aspen Plus are close to the experimental pyrolysis results.

With some of the considerations, the authors are interested in modeling the pyrolysis process of coconut waste using Aspen Plus software with coconut shell raw material to predict the results of pyrolysis in the form of bio-charcoal characteristics so that it is a consideration to do 100% substitution or partial substitution (co-firing) of coal. in a steam power plant (PLTU). This research is a simulation modeling of the pyrolysis process using Aspen Plus software with pyrolysis operating temperatures varying between 300 - 800°C. Several variables use the assumptions used in previous studies. The difference between this study and previous research is that the pyrolysis model used is different from previous research and model validation was carried out to determine the difference between the simulation results and the simulation in previous studies to determine the results of bio-charcoal and syngas.

METHODOLOGY

This research is a quantitative research which aims to determine the error value of the pyrolysis model and to determine the effect of pyrolysis operating temperature on the yield of bio-charcoal from coconut shell biomass. This research was conducted based on a research framework that can be seen in Figure 1. In this study, the authors model the pyrolysis process using Aspen Plus software. Then, the model is validated from the simulation results to find out the difference between the simulation results and the simulation results in previous studies as a comparison. In this simulation, the pyrolysis operating temperature was varied and then observed the characteristics, amount of bio-charcoal and syngas production.

Literature Study

A literature study was conducted to obtain references related to characteristics based on the results of the proximate, ultimate, calorific value of coconut shell analysis and references related to pyrolysis modeling using the Aspen Plus software. The characteristics of the coconut shell can be seen in Table 1.

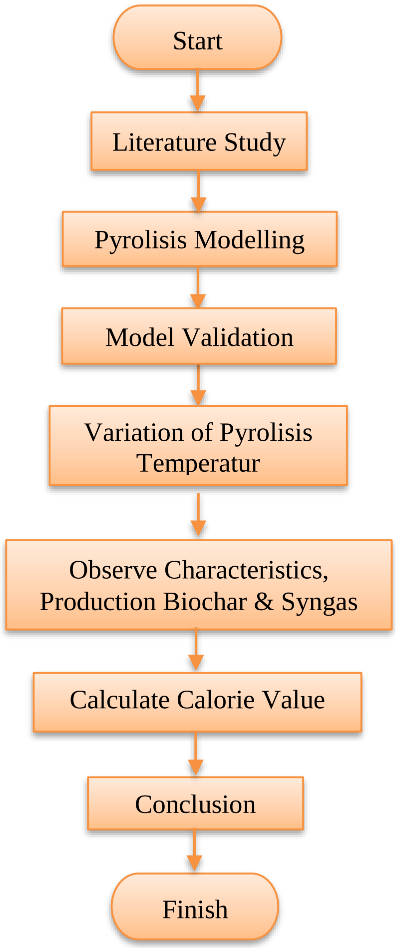

Figure 1. The research framework

Pyrolysis Modelling

Pyrolysis simulation modeling was carried out using Aspen plus software based on literature studies and then modifications were made for research novelty. The following is a pyrolysis modeling diagram using the Aspen Plus software presented in Figure 2.

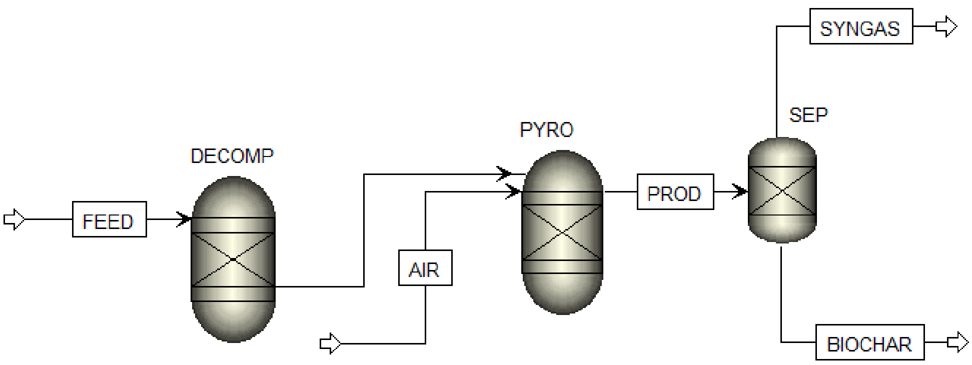

Figure 2. Pyrolysis modeling diagram using Aspen Plus

The pyrolysis process is simulated using the following assumptions (elkhalifa et al., 2019):

1. The model in steady state conditions
2. The model is in phase and chemical equilibrium
3. The process operates with a constant pressure of 1 atm (no pressure loss)
4. Fixed biomass flow rate is 100 kg/h

5. The process has no tar formation.

Model Validation

Simulation model validation was carried out by comparing the simulation results of bio-charcoal and syngas production to the results of previous studies.

$$Difference(\%) = 1 - \frac{Simulation\ result}{simulation\ refference} \quad (1)$$

Variation of Pyrolysis Temperature

The operating temperature is varied to see the effect of temperature on the characteristics of the coconut shell and the amount of bio-charcoal and syngas production.

Observe the Characteristics and Production Amount of Bio-charcoal and Syngas

Observe the effect of pyrolysis operating temperature variations on the characteristics and amount of bio-charcoal and syngas production. The simulated operating temperature is at 300°C, 400°C, 500°C, 600°C, 700°C, and 800°C.

Calculate Calorific Value

The characteristics of bio-charcoal are used to predict its heating value using the Dulong equation. The following is the equation for calculating the calorific value used (Menon et al., 2021):

$$HHV\ (kJ\ /kg) = 33823\ x\ C + 144250\ x\ (H - O/8) + 9419\ x\ S \quad (2)$$

$$LHV\ (kJ/kg) = HHV - 3240 \quad (3)$$

Where,

HHV = Highest Heating Value (kJ/kg)
LHV = Lowest Heating Value (kJ/kg)
O = Mass Fraction Oxygen
C = Mass Fraction Carbon
H = Mass Fraction Hydrogen
S = Mass Fraction Sulfur

Conclusion

The results of this research are to produce a modeling of the pyrolysis process using Aspen Plus software, and the pyrolysis products are bio-charcoal and syngas as well as predictions of calorific values.

RESULTS AND DISCUSSION

Based on the author's simulation results and reference simulation results, the total production of bio-charcoal, syngas, and syngas composition is shown in table 2. The difference is calculated using equation (1).

Table 2. Model validation: Simulation results versus previous reported study

	Simulation Results	**Literature (Visconti et al., 2015)**	**Difference (%)**
Biochar Yield	71.7	71	0.98
Gas Yield	28.3	29	2.41
CH_4	5.07	4.87	3.94
CO	19.50	22.4	12.95
CO_2	12.47	13.4	6.94
H_2	48.07	52.1	7.74
	Average		**5.8**

From the results of the simulations carried out using the Aspen Plus software, the characteristics of bio-charcoal with variations in pyrolysis operating temperature were obtained. The effect of pyrolysis operating temperature on the characteristics of bio-charcoal from coconut shells can be seen in table 3.

Table 3. The effect of pyrolysis operating temperature on the characteristics of coconut shell charcoal

Parameter (mass fraction)	Pyrolisis temperature 300°C	400°C	500°C	600°C	700°C	800°C
Ash (wt. %)	18.38	18.68	18.46	18.99	22.27	27.23
Carbon (C) (wt. %)	77.66	75.87	73.27	68.34	58.16	45.24
Hydrogen (H) (wt. %)	0.52	1.95	4.82	9.11	15.40	22.43
Nitrogen (N) (wt. %)	3.32	3.37	3.33	3.43	4.02	4.92
Sulphur (S) (wt. %)	0.00	0.00	0.00	0.00	0.00	0.00
Chlorine (CL) (wt. %)	0.12	0.12	0.12	0.13	0.15	0.18
Oxygen (O) (wt. %)	0.00	0.00	0.00	0.00	0.00	0.00

From table 3, it can be seen that the higher pyrolysis operating temperature, the carbon content becomes lower and the hydrogen content becomes higher, whereas the lower pyrolysis operating temperature, the carbon content becomes higher and the hydrogen content becomes lower. These two parameters affect the calorific value based on equation (2). To predict the yield of the heating value (LHV) of bio-charcoal, equation (2) and equation (3) are used. The results of the calculation of the calorific value (LHV) of coconut shell charcoal can be seen in table 4.

Table 4. Calculation results of coconut shell bio-charcoal calorific value

Parameter	Pyrolisis Temperature 300°C	400°C	500°C	600°C	700°C	800°C
LHV (MJ/kg)	23.79	25.25	28.50	33.03	38.66	44.44

From table 4 it can be seen that the higher pyrolysis operating temperature, the calorific value becomes higher. This is because at higher temperatures the hydrogen content becomes higher while at lower temperatures the hydrogen content becomes lower.

From the simulation results it can also be seen the level of syngas produced based on variations in pyrolysis operating temperature. The effect of pyrolysis operating temperature on syngas from coconut shells can be seen in table 5.

Table 5. The effect of pyrolysis operating temperature on syngas

Parameter (mole fraction)	Pyrolisis Temperature 300°C	400°C	500°C	600°C	700°C	800°C
CH_4 (%)	20.04	18.53	13.20	6.87	2.74	1.04
CO (%)	0.03	0.40	2.99	12.60	30.38	43.35
CO_2 (%)	19.20	21.60	22.25	18.72	9.85	2.90
H_2 (%)	3.14	11.11	25.27	39.88	47.57	49.67

From table 5 it can be seen that the higher pyrolysis operating temperature, the methane content (CH_4) becomes lower and the hydrogen content (H_2) becomes higher, whereas the lower pyrolysis operating temperature, the methane content (CH_4) becomes higher and the hydrogen content (H_2) becomes lower. These two parameters affect the heating value of the gas (Lv et al., 2004).

From the results of the simulations carried out, it was obtained the amount of bio-charcoal and syngas production with variations in pyrolysis operating temperature. The effect of pyrolysis operating temperature on the amount of coconut shell charcoal production can be seen in table 6.

Table 6. The effect of pyrolysis operating temperature on the amount of bio-charcoal and syngas production

Parameter	**Pyrolisis Temperature**					
	300°C	**400°C**	**500°C**	**600°C**	**700°C**	**800°C**
Bio-arang (%)	34.50	33.41	32.80	30.35	23.84	17.57
Syngas (%)	65.50	66.59	67.20	69.65	76.16	82.43

The graph of the effect of pyrolysis temperature on the heating value (LHV), ash content and the amount of coconut shell bio-charcoal can be seen in Figure 3.

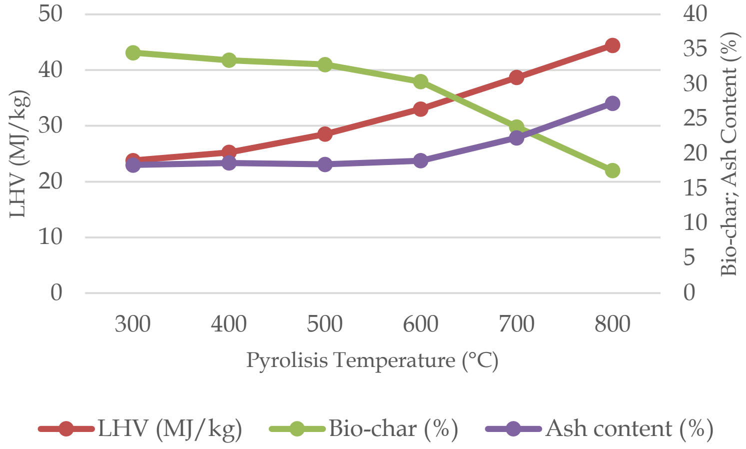

Figure 3. The effect of pyrolysis operating temperature on the amount bio-charcoal production

Figure 3 shows the effect of pyrolysis operating temperature on calorific value, amount of bio-charcoal production, and ash content. The higher pyrolysis operating temperature, the lower amount of bio-charcoal production, the higher the calorific value and ash content. While the pyrolysis operating at low temperatures produces a large amount of bio-charcoal production with low caloric value and ash content of the bio-charcoal. The results of this simulation are comparable to the results of previous studies, the higher pyrolysis operating temperature causes the evaporation process to be higher, causing the bio-charcoal to lose mass (Paulauskas et al., 2014). The simulation results show agreement with previous studies. The resulting calorific value will increase with the addition of the pyrolysis operating temperature in accordance with the results of previous studies (Zajec, 2009). This is because at higher temperatures the hydrogen content becomes higher while at lower temperatures the hydrogen content becomes lower. The graph of the effect of pyrolysis temperature on the syngas composition can be seen in Figure 4.

Figure 4 shows the effect of pyrolysis operating temperature on syngas composition. The higher pyrolysis operating temperature, H_2/CO content becomes higher dan CO_2/CH_4 content becomes lower. Meanwhile, the lower the pyrolysis operating temperature, H_2/CO content becomes lower dan CO_2/CH_4 content becomes higher. The effect of syngas composition on pyrolysis operating temperature has been confirmed in several pyrolysis and biomass gasification experiments (Dufour et al., 2009).

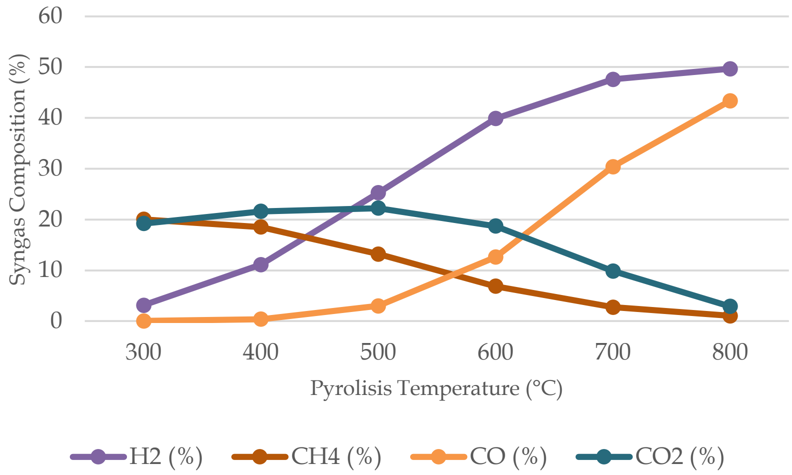

Figure 4. The effect of pyrolysis temperature on syngas composition

CONCLUSION

Based on the results of the research conducted, it can be concluded that the pyrolysis modeling made has an average mismatch value of less than 6%. The higher pyrolysis operating temperature, the lower amount of bio-charcoal production, the higher the calorific value and ash content. While the pyrolysis operating at low temperatures produces a large amount of bio-charcoal production with low caloric value and ash content of the bio-charcoal. Syngas simulation result show The higher pyrolysis operating temperature, H_2/CO content becomes higher dan CO_2/CH_4 content becomes lower. Meanwhile, the lower the pyrolysis operating temperature, H_2/CO content becomes lower dan CO_2/CH_4 content becomes higher. Simulation results of coconut shell pyrolysis with yield maximum of bio-charcoal occurred at an operating temperature of 600°C which produces a total of 30.35% bio-charcoal, a calorific value (LHV) of 33.03 MJ/kg, and an ash content of 18.99%. While the simulation results of coconut shell pyrolysis with maximum syngas yield occurred at an operating temperature of 800°C which produced 82.43% syngas, 49.67% high H_2 and 2.90% low CO_2.

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