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Characterization Product of Bio-char and Bio-oil from Pyrolysis of Castor Bean and Rubber Seed Shell

Ratu Diva Angelika[*1], Irawan Rusnadi[2], KA Ridwan[3]
[1 2 3] Chemical Engineering Department, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar, Palembang, 30139, Indonesia
*Corresponding Author's e-mail : ratuangel106@gmail.com

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ABSTRACT
Indonesia has abundant biomass resources, agricultural waste such as rubber seed shells and castor beans are one of them. One way to process biomass into alternative energy is by pyrolysis method. Pyrolysis is a process in which chemical compounds are broken or the chemical structure of organic matter is broken through a heating process in a reactor without oxygen or with little oxygen. Most pyrolysis uses only one raw material. In this case, to determine the optimal pyrolysis product, observations were made on variations in operating temperature and variations in the ratio of the two materials with operating temperatures of 350°C and 250°C variations in raw material composition (100:0, 75:25, 50:50, 25:75, 0:100), with the addition of natural zeolite catalyst. Product analysis includes % yield of pyrolysis products (bio-char, bio-oil, syngas), proximate analysis of bio-char, calorific value, flash point and CH4 content contained in syngas. The results of this study show the influence of operating temperature variations where the operating temperature of 350°C is most optimal in obtaining % yield of bio-oil and syngas, but for the most optimal operating temperature in obtaining biochar yield is at 250°C.

Keywords: *Biomass, Castor Bean Seeds, Pyrolysis, Rubber Seed Shells*

1. INTRODUCTION

Indonesia's average energy demand growth over the past ten years has been around 7%. With relatively few fossil fuel resources, Indonesia faces challenges in providing sustainable energy. Indonesia has a population of about 3.4% of the world's population, although its fossil fuel reserves are much smaller. Indonesia does have great potential for renewable energy [4].

Biomass resources in Indonesia are estimated at 49,810 MW, including plants and waste. One of them comes from crop waste such as rubber seed husks and castor beans. According to the study of [9], castor beans have an oil content of 54%. It also has a heating value of 35.58 MJ/kg, an acid value of 3.08 mg KOH/g, a flash point of 290°C, a viscosity of 50.80 cSt, and a density of 0.0181 g/cm3. One of the underutilized crop wastes is rubber seed husks [3]. Rubber seed shell contains 66.4% hemicellulose and 25.8% cellulose. Waxes, fats, resins and flavonoids contribute to the remains of the shell [8].

Pyrolysis is one method that can convert biomass into energy. Pyrolysis combustion can produce three main products: gas, liquid smoke (bio-oil), and charcoal. Charcoal is a fuel with high calorific value and can be used as activated carbon. Liquid smoke can be used as a food preservative or for certain products. However, the gas produced can be burned directly. Pyrolysis produces two types of gas: non-condensable gas (CO, CO_2, CH_4, etc.) and condensable gas (tar). The condensation process of non-condensable gas produces oil.

The quality and yield of each pyrolysis product are strongly influenced by several parameters, including temperature, heating rate, residence time, and the type of biomass feedstock used. Higher temperatures generally favor the formation of gaseous products, while lower temperatures tend to produce more bio-char and bio-oil. Therefore, optimizing these process conditions is essential to obtain the desired product distribution and improve energy recovery efficiency.

One of the many variables that can affect the yield of pyrolysis products is the temperature used during production and the catalyst used. Variations in temperature during production can affect the time required for pyrolysis, while variations in composition and catalyst use affect the quality of the pyrolysis products produced [10].

Most pyrolysis studies typically employ a single type of feedstock. In this study, variations in operating temperature and the composition of two feedstocks—rubber seed shells and castor beans—were investigated to determine the optimal conditions for producing the desired pyrolysis products

2. MATERIAL AND METHODS

2.1 Tools and Materials

This study used raw materials in the form of rubber seed shells and castor beans with a total of 15 kg which were used for 10 runs. Each run uses 1.5 kg of raw material with a raw material composition ratio of 100:0, 25:75, 50:50, 75:25, 0:100 (rubber seed shells: castor beans), and the addition of 2 kg of natural zeolite catalyst. The equipment used in this research is a set of pyrolysis tool.

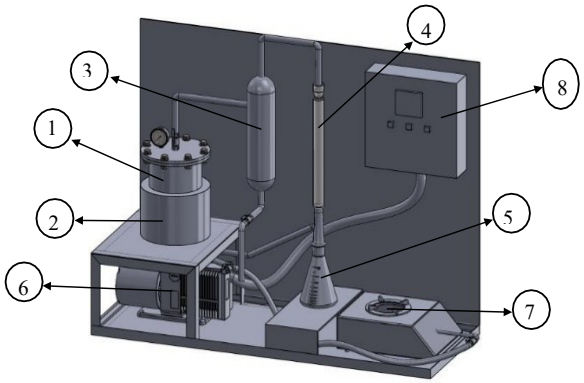


Figure 1. Pyrolysis Set

Description :
1. Pyrolysis Reactor
2. Heater
3. Separator
4. Condenser
5. Condensate Tank
6. Vacuum Pump
7. Gas Stove
8. Control Panel

2.2 Methods

The parameters measured in this study were the characteristics of the pyrolysis products, which depended on the raw material ratio, operating temperature, and the type of catalyst used. The research variables consisted of fixed variables and independent variables. The fixed variable was the raw material mass, maintained at 1.5 kg for each run, with 3% natural zeolite catalyst added. The independent variable was the ratio of raw material composition between rubber seed shells and castor beans, which was varied at 100:0, 25:75, 50:50, 75:25, and 0:100 (% w/w). The operating temperatures were set at 350 °C and 250 °C, with one temperature selected for each experimental run.

The pyrolysis products, namely bio-char, bio-oil, tar, and syngas, were analyzed to determine their respective yields. The amounts of bio-char and bio-oil were measured using an analytical balance and a measuring cylinder, respectively, while the yield of tar was determined using a measuring cup. The yield of pyrolysis products was calculated using the following equation

$$\%yield\ bio-oil = \frac{bio\text{–}oil\ mass}{mass\ of\ raw\ materials} \times 100\% \quad (1)$$

$$\%yield\ bio-char = \frac{bio-char\ mass}{mass\ of\ raw\ materials} \times 100\% \quad (2)$$

$$\%yield\ tar = \frac{tar\ mass}{mass\ of\ raw\ materials} \times 100\% \quad (3)$$

$$\%yield\ syngas = \%\ yield\ bio\ char - \%yield\ bio\ oil - \%yield\ tar \quad (4)$$

After calculating the yield of pyrolysis products, the next step is to analyze the bio-char, in the form of proximate analysis, and calorific value which refers to SNI 1683-2021. For bio-oil, a characteristic analysis is carried out, namely density and acidity level in terms of bio-oil quality requirements (SNI 8985: 2021), as well as analyzing the flash point (Flash Point Kholer GB/T3536-2008) and calorific value using a bomb calorimeter. As well as analyzing syngas products using a multi gas detector.

2.3 Research Flowchart

This research process can be observed in the following diagram

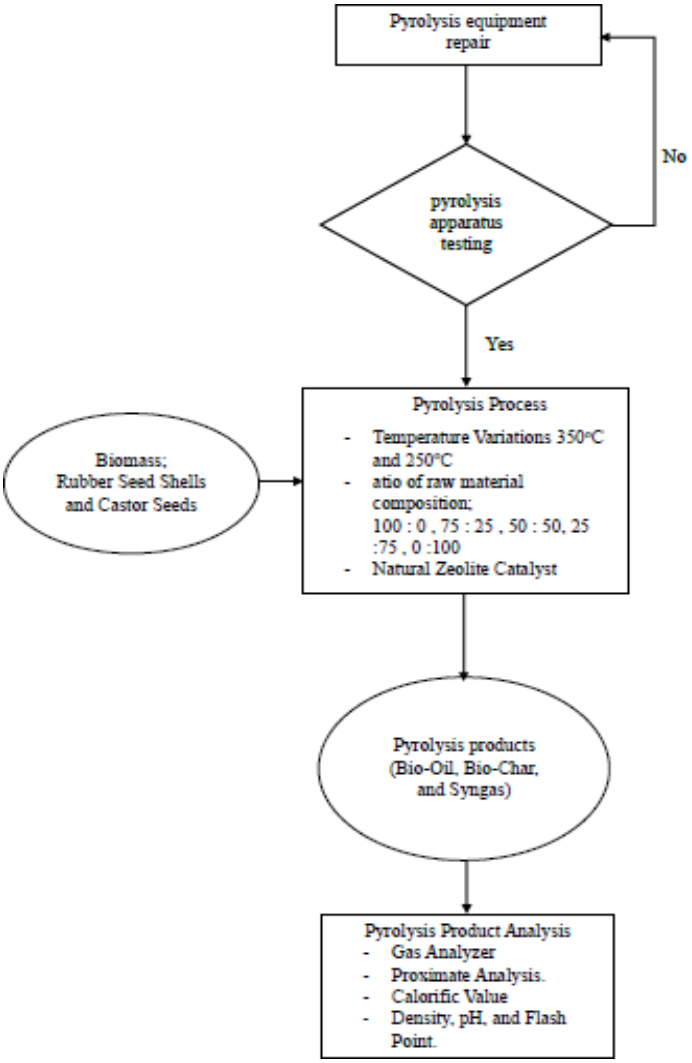


Figure 2. Pyrolysis research procedure

3. RESULTS AND DISCUSSIONS

The research focused on knowing and analyzing the effect of temperature and variation of raw material mixing composition on the products of pyrolysis (*bio-char, bio-oil, syngas*).

3.1 Effect of Temperature and Feedstock Composition Ratio on Bio-Char Product

In bio-char products, the type of raw material and operating temperature affect the amount of yield produced. The following char yield results can be seen in Figure 4.1 below:

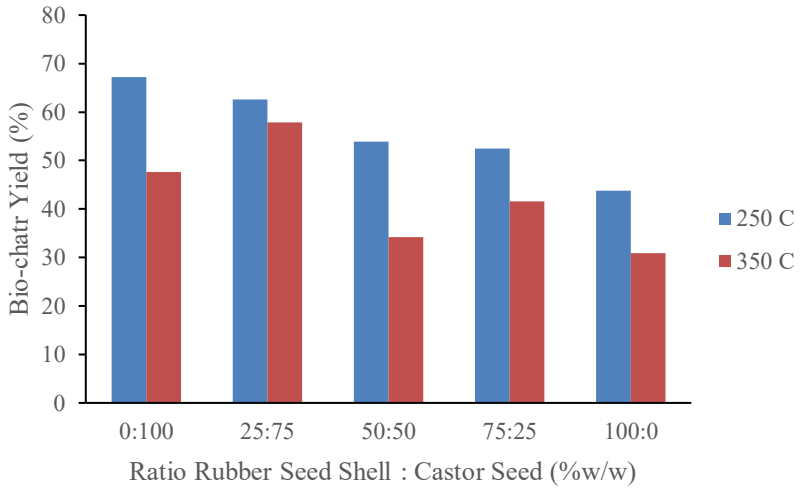


Figure 3. Effect of Temperature and Feedstock Composition Ratio on Bio-Char Yield %

Figure 3 shows that the effect of temperature and type of biomass used in the pyrolysis process is very significant on the % yield of biochar. Where the highest biochar yield, which is 67.2%, is found in the composition of 100% castor beans with a temperature of 250°C and the lowest biochar yield, which is 30.9%, is found in the composition of 100% rubber seed shells with a temperature of 350°C. This happens because higher temperatures generally reduce biochar yield while increasing biochar yield. This happens because higher temperatures generally reduce biochar yields while increasing bio-oil and gas yields.

The type of biomass also affects the amount of char produced. This is due to the substances contained in the biomass. The more cellulose and hemicellulose content in biomass, the less char is produced, it is because cellulose and hemicellulose substances are more quickly decomposed into steam and ash [11]. The biochar yield in figure 3 is still quite high ranging from 30% - 67%. This happens because the type of pyrolysis carried out is slow pyrolysis. This type of pyrolysis occurs at low temperatures, namely <400° C, which in this study used a temperature of 350°C, so that the main product is biochar. When slow pyrolysis takes place, the biomass is heated slowly in the absence of oxygen to a relatively low temperature of less than 400°C for a long period of time. Slow pyrolysis can produce good quality char using low temperatures and heating rates [7]. for analysis of the characteristics and calorific value of bio-char can be seen in table 1 below.

Table 1. Results of Proximate Analysis and Calorific Value of Bio-char

Parameters	Temperature						Char Standar (SNI 1683:2021)
	350°C			250°C			
	S1	S2	S3	S1	S2	S3	
Moisture Content (%)	3,75	5,27	6,22	9,11	4,53	4,44	≤10
Volatile Substance Concentration (%)	9,56	16,2	8,7	6,14	11,4	11,7	10 – 17
Ash Content (%)	10,7	20,5	13,5	6,12	14,3	18,17	≤4
Fixed Carbon (%)	76	58	71,5	78,63	69.7	65,69	≥79
Calorific Value (cal/gr)	4022	6518	6129	3075	4515	4795	6000 - 6500

Sample 1 (1) is a raw material composition of 100% castor beans, sample 2 (2) is a raw material composition ratio of 50% castor beans and 50% rubber seed shells, while sample 3 (3) is a raw material composition of 100% rubber seed shells.

Based on the data in table 3.1 shows that operating temperature affects the characteristics of bio-char. Where the higher the operating temperature, the higher the flying substance content, ash content, and heating value of bio-char. Regarding the moisture and fixed carbon contents of the bio-char, according to the analysis results shown in Table 1, the higher the feeding temperature, the lower the water content and bound carbon content in bio-char. from the statement of these data that are not in line with previous research is found in the water content of bio-char, where according to previous studies found that the higher the process temperature, the lower the water content [2].

Based on the data analysis of the characteristics and calorific value of bio-char contained in table 1, it shows that the characteristics of biochar in the data have met the char standard (SNI 1683: 2021), except for ash content, bound carbon content and calorific value in the bio-char characteristic analysis data has not met the standard.

3.2 Effect of Temperature and Feedstock Composition Ratio on Bio-Oil Product

In bio-oil products, the type of biomass and operating temperature affect the yield produced. The following bio-oil yield results can be seen in figure 4 below.

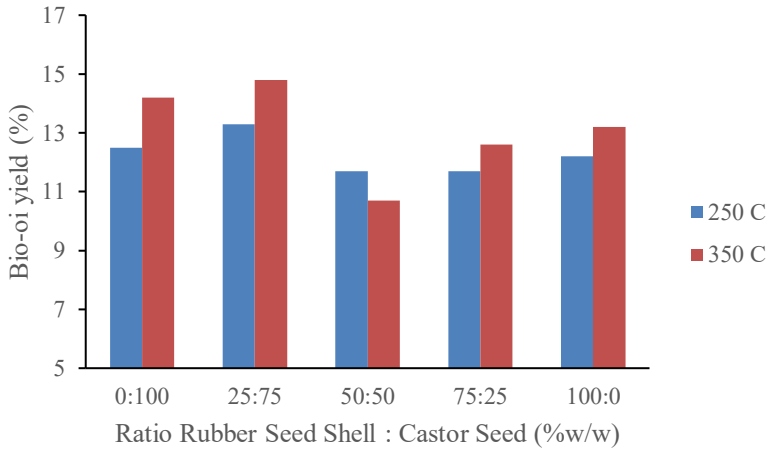


Figure 4. Effect of Temperature and Feedstock Composition Ratio on Bio-Oil Yield %

Based on the analysis data seen in figure 4, it shows that the bio-oil yield % increases with increasing operating temperature. Where the largest bio oil yield is produced at an operating temperature of 350 ° C, which is 14.8%. According to [10] the higher the temperature and the longer the time, the more liquid smoke is produced. This is because the longer the combustion time, the more smoke is produced and the higher the temperature, the more biomass solids are oxidized and decomposed into smoke and in turn into liquid. Based on the analysis data of volatile substance content contained in Figure 4, the composition with the dominant castor bean produces higher bio oil yield at each operating temperature compared to the composition of the dominant rubber seed shell at each operating temperature. This means that there is an influence of the type of biomass on the yield of bio oil. bio oil produced. According to [4], lignin content affects the yield of bio-oil produced, the higher the lignin content, the greater the yield of bio-oil produced. Based on research conducted by [9], castor beans have an oil content of 54% and already meet the ideal requirements of a fuel, namely its calorific value of 35.58 MJ/kg. This is what causes the bio oil yield from castor bean raw materials to be higher than rubber seed shells, where according to [8], rubber seed shells only contain 18.74% lignin.

Temperature and feedstock composition ratio are key factors influencing the pyrolysis behavior and the resulting bio-oil characteristics. In the co-pyrolysis of castor bean shell and rubber seed shell, variations in these parameters affect the yield, viscosity, and chemical composition of the bio-oil, which in turn determine its potential as a renewable energy source. Data analyzing the characteristics and calorific value of bio-oil are in table 2 below

Table 2. Characteristic and Calorific Value of Bio-oil

Parameters	Temperature						*Bio-oil* Standar (SNI 8985:2021)
	350℃			250℃			
	1	2	3	1	2	3	
Density (gr/Ml)	0,963	0,979	1,03	0,97	0,963	1,13	1,005-1,050
pH	6,9	4,02	3,43	6,42	3,85	3,24	1,5-4,5
Flash Point (℃)	88	210	220	241	243	-	≥ 52
Calorific Value (cal/gr)	8405	4071					5,374-7,213

Sample 1 (1) contained 100% castor beans, sample 2 (2) contained 50% castor beans and 50% rubber seed shells, whereas sample 3 (3) contained 100% rubber seed shells.

Based on the data contained in table 2, it shows that the higher the temperature, the higher the flash point and density of bio-oil, this for the bio-oil density data studied is inversely proportional to previous research, which states that the higher the operating temperature, the lower the bio-oil density value [12]. for the calorific value of bio-oil at 350°C with a raw material composition of 100% rubber seed shells and a ratio of 50:50 (rubber seed shells: castor beans) has approached the bio oil standard in accordance with SNI. 8985:2021

3.3 Effect of Temperature and Feedstock Composition Ratio on Syngas Product

The graph of the effect of variations in raw material composition and temperature on the syngas yield produced in the study can be seen in figure 5.

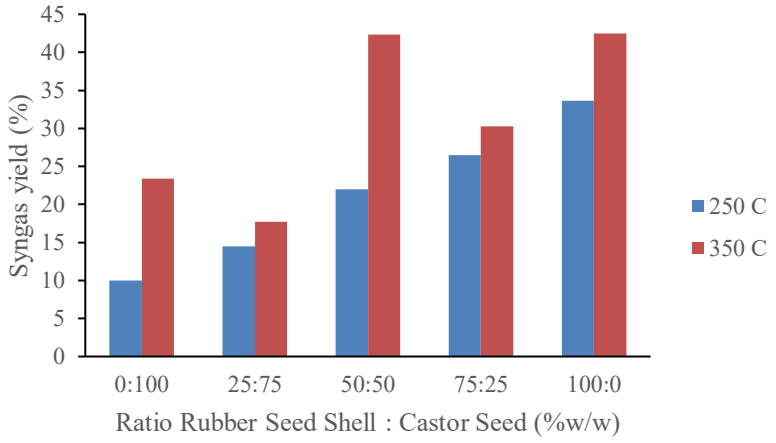


Figure 5. Effect of Temperature and Feedstock Composition Ratio on Syngas Yield %

Increasing the pyrolysis reaction temperature causes gas and liquid yields to increase while char yields decrease [4]. The vaporized biomass decomposition gas is then condensed to produce bio-oil and non-condensable gases such as (CH_4, H_2, CO_2, and CO), the gas formed can be burned directly so that it can be used as energy recuperation or used as syngas [10]. From the analysis data shown in figure 5, it shows that the higher the operating temperature, the higher the syngas yield. Where the highest syngas yield content is produced at an operating temperature of 350°C, which is 41.9% and the lowest syngas yield content is produced at an operating temperature of 250°C, which is 9%. increasing temperature produces higher gas yields and lower liquid and charcoal yields [1].

Based on figure 5, it shows that the composition of raw materials dominated by rubber seed shells has a higher syngas yield than the composition of raw materials dominated by castor beans. In this case, the effect of raw material composition contributes to the syngas yield %. The main parameters affecting syngas production include feedstock type, temperature, catalyst, and reactor configuration. Higher temperatures generally increase syngas yield and change its composition [11]. Previous studies revealed that co-feeding biomass and methane at high temperatures produces

syngas with enriched hydrogen content. The syngas composition depends on the reactant ratio, and temperature is the dominant factor affecting the performance indicators. Theoretical and experimental studies show that hydrogen is easily evolved from biomass and methane [5]. The analyzed data of CH_4 content in syngas is shown in Figure 6.

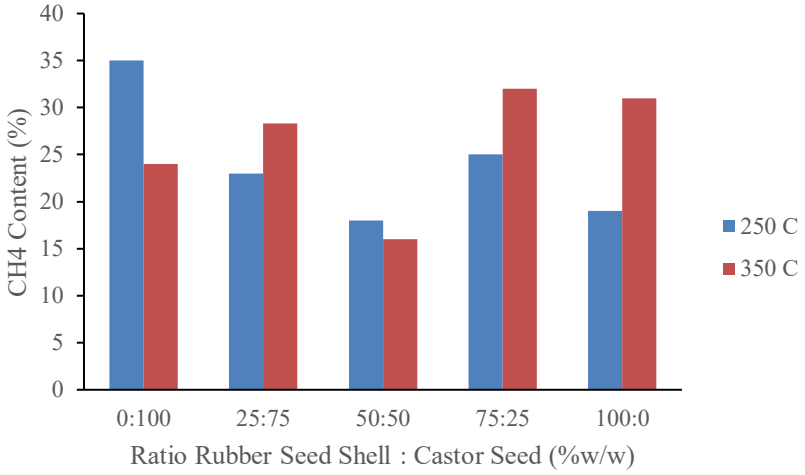


Figure 6. Effect of Temperature and Feedstock Composition Ratio on Syngas CH4 Content

Based on the data in figure 6 shows that 3 data in the annealing shows that the higher the operating temperature, the CH_4 content in the syngas will increase. And 2 other analysis data show that the higher the operating temperature, the CH_4 content in syngas will decrease. According to [1], the volatile content of solid fuel indicates the concentration of organic hydrocarbon content in biomass feedstock, this parameter not only helps determine the amount of fuel produced but also the ability of biomass feedstock to ignite and perform thermal conversion, the volatile content can be pyrolyzed into small molecules such as CO, H_2, CH_4, etc., which will increase the yield of syngas.

4. CONCLUSIONS

The results indicate that both the raw material composition ratio and temperature have a significant influence on the pyrolysis product yields. The highest bio-char yield (67.2%) was achieved at 250 °C using 100% castor beans as the feedstock. While in bio-oil, the highest yield was obtained at an operating temperature of 350°C, with a ratio of raw material composition 25:75 (rubber seed shell: castor bean) which amounted to 14.8%. Meanwhile, the highest syngas yield was obtained at 350°C with a raw material composition ratio of 50:50 (rubber seed shells: castor beans) which amounted to 41.9%.

The effect of the ratio of raw material composition and temperature on the quality of pyrolysis products, obtained in bio-char products with optimal quality at 350°C operating temperature with a raw material composition of 100% rubber seed shells with a calorific value of 6129.56 cal/gr. Bio-oil products with optimal quality are obtained in the pyrolysis process with a temperature of 350°C with a raw material composition of 100% castor beans and have a calorific value of 8405.1755 cal/gr. Syngas products with optimal quality are obtained in the pyrolysis process with an operating temperature of 250°C with a raw material composition of 100% castor beans producing the highest CH_4 content of 35%.

REFERENCES

[1] Fernandez, *et al*. (2022). 'Role of Temperature in Biomass Steam Pyrolysis in Conical Spouted Bed Reactor', *Social Science Research Network.*

[2] Iskandar, T., Rofiatin, U. (2017). Karakteristik Biochar Berdasarkan Jenis Biomassa Dan Parameter Proses Pyrolisis. Jurnal Teknik Kimia, Vol 12, No 1.

[3] Jaya, Darma Jaka; Sandri, Dwi; Setiawan, Agusten;. (2019). Pembuatan Asap Cair dari Cangkang Biji Karet dan Aplikasinya Sebagai Koagulan Lateks. JURNAL TEKNOLOGI AGRO-INDUSTRI.

[4] Kasmaniar. (2023). Pengembangan Energi Terbarukan Biomassa dari Sumber Pertanian, Perkebunan dan Hasil Hutan: Kajian Pengembangan dan Kendalanya. *Jurnal Serambi Engineering*.

[5] Mardiah. et al. (2014). Studi Peningkatan Yield Tar Co-Pirolisis Batubara dan Tandan Kosong Kelapa Sawit. Seminar Nasional Teknologi Industri Hijau I. Semarang. Hal. 90-95.

[6] Mensah, et al. (2022). 'Recent Devlopment of Biomass and Plastic Co-Pyrolysis for Syngas Production', Chemical Science International Journal, pp 41-59.

[7] Patra, B. R., Nanda, S., Dalai, A. K., and Meda, V. 2021. Slow pyrolysis of agrofood wastes and physicochemical characterization of biofuel products. Chemosphere. 285: 131431.

[8] Prabawa, I. D. G. P., & Miyono, M. (2017). Mutu Biopelet dari Campuran Cangkang Buah Karet dan Bambu Ater (Gigantochloa atter) (The Quality of Biopellet from Rubber Seed Shell and Ater Bamboo (Gigantochloa atter). Jurnal Riset Industri Hasil Hutan, 9(2), 99–110. https://doi.org/10.24111/jrihh.v9i2.3524

[9] Rabie, A.M., Mohammed, E.A. and Negm,N.A. (2020) 'Feasibility of modi fi ed bentonite as acidic heterogeneous catalyst in low temperature catalytic cracking process of biofuel production from nonedible vegetable oils', 254(2018), pp. 260–266.

[10] Ridhuan, Kemas., Irawan, Dwi., Inthifawzi, Rizki. (2019). Proses Pembakaran Pirolisis dengan Jenis Biomassa dan Karakteristik Asap Cair yang Dihasilkan. Jurnal Program Studi Teknik Mesin UM Metro, 70-72.

[11] Rosyadi, I., Wahyudi, H., Satria, D., Yusvardi, Y., & ... (2018). Analisis Hasil Pyrolisis Pada Limbah Biomassa Tongkol Jagung Dengan Kayu Akasia. Prosiding , 229–234. https://ejournal.itn.ac.id/index.php/seniati/ar ti cle/download/788/711

[12] Wulandari, Y. R., Chen, S. S., Hermosa, G. C., Hossain, M. S. A., Yamauchi, Y., Ahamad, T., Alshehri, S. M., Wu, K. C. W., and Wu, H.-S., (2020), Effect of N2 flow rate on kinetic investigation of lignin pyrolysis, Environmental Research, 190, 109976