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Syngas Production from Updraft Co-Gasification Process Using Compost, Coffee Husk, and Coal as a Raw Materials

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Abstract

The coffee husk biomass from plantation products and compost from household waste processing is currently underutilized. Therefore, efforts are needed to enhance the value of compost and coffee husk as raw materials for producing syngas through co-gasification processes. Due to the low calorific values of these materials, it is necessary to add materials with higher calorific values. In this study, low-quality coal was used for this purpose. The research aims to investigate the influence of airflow rate and mass composition of raw materials on the quality of syngas which produced through the updraft co-gasification process. The stages conducted in this study include raw material pretreatment and characterization, gasification process, and syngas analysis. The experimental variables used were the percentage composition of raw materials, consisting of coffee husk and coal, and airflow rates of 10, 15, 20, and 25 liters per minute. The research results indicate that syngas with the highest Lower Heating Value (LHV) was produced from the co-gasification process using raw materials with a composition of 75% coffee husk and 25% coal, along with an airflow rate of 20 liters per minute. The LHV of the syngas was 5045.56 kJ/m^3, consisting of 20.28% CO and 6.89% H_2.

INTRODUCTION

Indonesia, as the fourth most populous country in the world in 2018 with a population of over 260 million people, has the potential to become a nation with a very significant waste accumulation. The increase in population causes enormous changes to the environment (Weber & Sciubba, 2019). Garbage is one of the main problems in cities in Indonesia. Based on data from the Ministry of Environment and Forestry (KLHK), Indonesia produces 21.88 million tons of waste in 2021. With the increasing volume of landfills and wasteful waste management, this will create a bad condition in the future.

Waste processing in Malang City, to be precise at TPA Supit Urang, uses a sanitary landfill system. This waste processing is carried out by collecting and piling up waste on land that has been excavated, then compacting it and filling it with soil, this waste treatment system is often or the most widely used in Indonesia.

In addition to sanitary landfills, waste processing that is carried out at the Supit Urang TPA is composting. The capacity of the composting site at the Supit Urang TPA is 15 tons, of 100% of the city's waste including garden waste and market waste, only 40% manages to become compost. The amount of compost in the very abundant Supit Urang landfill is as much as 6 tons in one harvest, compost has the potential to be used as a source of renewable energy

Based on PP No. 79 of 2014 concerning national energy policy, the Indonesian government has a target to achieve an optimal primary energy mix (ESDM, 2020). The Indonesian government is targeting that in 2025 the role of new energy and renewable energy will be at least 23% and the role

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of coal will be at least 30%, while in 2050 the role of new energy and renewable energy will be at least 31% and the role of coal will be at least 25%. This regulation aims to reduce national energy dependence on fossil fuels. This dependence can be reduced by developing new renewable energy by utilizing biomass and coal in co-gasification technology.

One of the appropriate processes for processing solid waste such as biomass and coal to become renewable energy is co-gasification. Co-gasification is the thermochemical conversion of two mixtures of solid fuels into flammable gaseous fuels (Wijaya et al., 2017). Most studies have identified that gasification with multiple feedstocks (co-gasification) is more beneficial, especially the combination of coal and biomass (Raj et al., 2022).

The main material that is often used in the gasification process is biomass. Biomass raw materials used in the gasification process usually contain high calorific values because they contain elements of carbon, oxygen and hydrogen. The high calorific value is influenced by the carbon content in lignin compounds from biomass (Nawawi et al., 2018). One of the biomass that can be used as gasification material is coffee husk.

Coffee is a type of plantation crop that has high economic value. In 2020 Indonesia will be able to produce 762 thousand tonnes of coffee (BPS, 2022). According to the Directorate General of Plantations, in 2020 as many as 48,498 tons of coffee were produced in East Java. The four regions with the highest coffee production in East Java are Banyuwangi Regency, Jember Regency, Malang Regency and Bondowoso Regency. PTPN-XII Bangelan is one of the coffee-producing industries in Malang Regency with an area of 850 ha with a production capacity of 60 tons/day in 2021. One coffee fruit contains 55.4% coffee beans, 28.7% fruit husk, 11.9% % shell husk and 4.9% in the form of mucus (Siahaan, 2018). So that it has the potential to produce abundant waste from processing coffee beans around 50-60% (Saisa & Syabriana, 2018). Coffee husk waste is a type of biomass resulting from the processing of coffee beans which is generally brownish yellow in color, has a flat round shape, contains 20.30% pentose, 24.40% lignin and 45.90% hexose (Siahaan, 2018). Coffee husk waste contains 47.67% carbon (C), 43.38% oxygen (O), 6.2% hydrogen (H), and 0.7% nitrogen (N) so that coffee husks can be used as gasification fuel (Siahaan, 2018).

Apart from biomass, another material that can be used as the main ingredient for gasification is coal. According to the Ministry of Energy and Mineral Resources, coal reserves in Indonesia are estimated at 91 billion tons with production rates ranging from 200-300 million tons per year. This provides certainty sustainability for the coal-consuming industries. The coal used in the gasification process is low rank coal with lignite and sub-bituminous types. Utilization of coal as fuel for gasification because coal has a higher calorific value than biomass. Coal contains 69.16% carbon (C), 25.38% oxygen (O), 5.14% hydrogen (H), and 0.14% nitrogen (N) (Trifiananto, 2015).

Based on the description of the background and previous research, compost, coffee husks and coal have the potential to be used as alternative fuels in the form of syngas. This study aims to utilize compost, coffee husks, and coal using an updraft type co-gasification process to produce syngas. The research object is a mixture of compost, coffee husk, and coal as an element of the renewal of this research. The variables that will be used are the air flow rate from the compressor and the percentage of mass composition between compost, coffee husks, and coal to determine the effect on the quality of the syngas produced.

MATERIALS AND METHODS

Materials

The raw materials used in this study were compost taken from the Supit Urang landfill in Malang City, coffee husks taken from PTPN XII Bangelan East Java, and coal taken from Power Generation Industry in East Java.

Methods

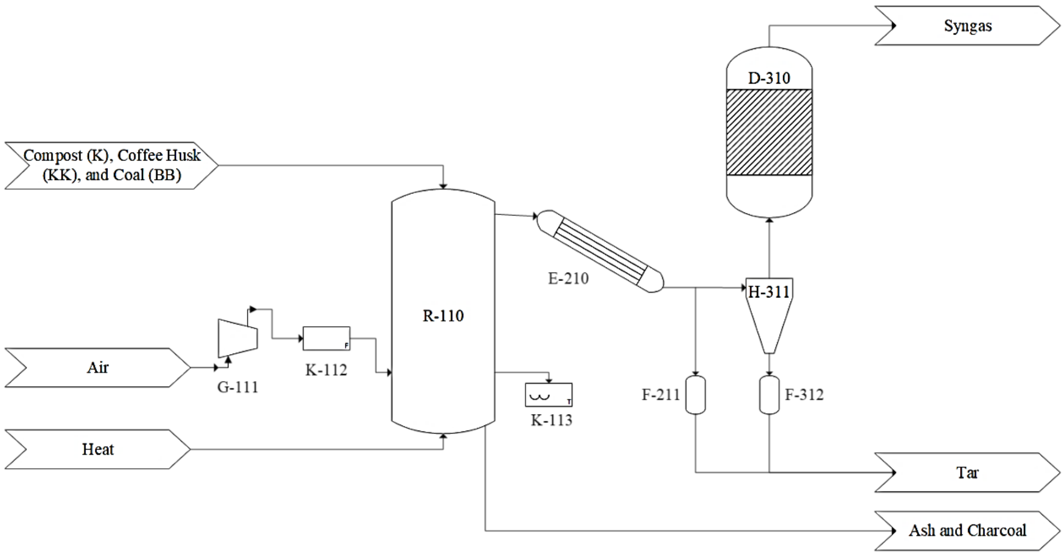
This research was conducted through several stages: 1. Pretreatment of raw materials, 2. Characterization of raw materials, 3. Co-gasification process, 4. Syngas analysis of co-gasification results.

Raw Material Pretreatment

At this stage the raw material was dried at 120°C for 2 hours. This process aims to reduce the water content in the raw material.

Characterization of Raw Materials

At this stage, raw materials were proximately analyzed including moisture content,



Information :

G-111	: Compressor	F-211	: Tar storage tank
K-112	: Air flowmeter	H-311	: Cyclone
R-110	: Gasification reactor (gasifier)	F-312	: Tar storage tank
K-113	: Thermocouple	D-310	: Filters
E-210	: Condenser		

Figure 1. Scheme of gasification equipment.

ash content, volatile matter content, and fixed carbon as well as calorific value analysis.

Co-Gasification Process

The raw material was weighed as much as 3 kg (the composition of the raw material according to the variation) was then put into the gasification reactor. The compressor was turned on and the airflow rate that enters the gasifier was adjusted according to the variation. Turn on the burner to start the co-gasification process. The process was carried out for 3 hours with a co-gasification process temperature of 500°C. The schematic of the equipment used in the gasification process is shown in Figure 1.

Raw materials in the form of compost (K), coffee husks (KK), and coal (BB) are fed into the gasifier (R-110). After the raw materials were entered, the compressor (G-111) was turned on to supply oxygen in the co-gasification process. The burner was turned on as a heat source to convert raw materials into syngas. after that the co-gasification process was carried out for 3 hours at a temperature of 500°C. Temperature was monitored via a thermocouple (K-113). The syngas resulting from co-gasification comes out through the top of the gasifier and then enters the condenser (E-210). In the condenser, the syngas will be separated from other particles by changing the other particle's phase from gas to liquid which was then stored in a tank (F-211) as tar. After leaving the condenser, the syngas will then enter the cyclone (H-311) to separate the solid and tar particles that were still in the syngas. After passing through the cyclone, the syngas enters the filter (D-310). In the filter there were three types of filters, namely glasswool, activated charcoal, and also silica gel. The output of the filter was clean syngas which was then used as a sample to test its content (CO and H_2).

Syngas Analysis of Co-Gasification Results

Syngas analysis includes composition, Lower Heating Value (LHV), and yield. Analysis of the composition of the syngas includes the gas content of carbon monoxide (CO) and hydrogen (H_2). LHV analysis was performed using empirical equations. Syngas yield analysis was carried out using data on the mass of charcoal, ash, and tar derived from the by-products of the co-gasification process.

RESULTS AND DISCUSSION

Characterization of Raw Materials

Characterization of raw materials in this study includes proximate analysis and heating value. Proximate analysis in the form of moisture

Table 1. Characterization of raw materials.

Material	Moisture (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon(%)	Caloric Value (kcal/kg)
Coffee husk (KK)	9.02	1.18	76.24	13.56	3282.37
Coal (BB)	10.42	5.66	21.63	62.29	4939.49
Compost (K)	9.76	35.82	53.39	1.03	1341.57

content, ash content, volatile matter, and fixed carbon was carried out gravimetrically. The results of the proximate analysis and the calorific value of coffee husk (KK), compost (K) and coal (BB) can be seen in Table 1.

The results of the proximate analysis show that the moisture content of the raw materials is in accordance with the ideal conditions of co-gasification raw materials. The ideal water content for gasification raw materials is less than 20% (Ardiansyah et al., 2017). The raw materials used for the gasification process are generally expected to have a low moisture content value. High water content can reduce the thermal efficiency of gasification, because most of the heat energy is wasted on evaporation of water content n biomass, so that syngas has a low caloric value (Ma'arif et al, 2019).

Proximate analysis of raw materials shows that the ash content of compost is much higher than that of coffee husks and coal. High ash content can cause slagging clinker, scale and excess tar formation in the gasifier (Kuku, 2014). This is caused by melting and agglomeration of the ash contained in the gasification feedstock. In addition, excess ash content can inhibit the combustion process of co-gasification raw materials by means of silica reacting with oxygen to become ash (Siahaan, 2018).

Volatile matter (VM) is the amount of substance lost when the material is heated at a predetermined temperature and time (after being corrected by the water content). Evaporating volatiles consist mostly of flammable gases such as hydrogen, carbon monoxide and methane (Hamdani & Oktarini, 2014). According to Kuku (2014) VM contained in biomass is 70% -90% and coal is ± 20% so that the results of VM analysis in this study are appropriate.

The last proximate analysis performed is Fixed Carbon (FC). FC states the amount of carbon contained in the residual material after the volatile matter has been removed. According to Hamdani & Oktarini (2014) the content of VM and FC plays the most role in determining the heating value of a material. VM and FC are used as calculations to assess fuel quality, namely in the form of fuel ratio values. In this study the FC of compost was much smaller than coffee and coal husks

Characterization of co-gasification feedstock besides proximate analysis is calorific value analysis. The calorific value is the amount of energy produced from burning 1 kg of fuel (Srinivas, 2017). The calorific value of coal is 4939.49 kcal/kg which indicates that the coal is a low quality coal with sub-bituminous type. According to Bono et al. (2017) sub-bituminous type coal has a heating value of 4600 – 6400 kcal/kg.

Syngas Composition

The gases analyzed were carbon monoxide (CO) and hydrogen (H_2). Suhendi et al. (2016) explained that the reaction for the formation of syngas (CO and H_2) consists of several reactions, namely the boudouard reaction, steam-carbon reaction, and water-gas shift reaction. The results of the analysis of the gas composition of CO and H_2 can be seen in Table 2 and Table 3.

The independent variable of air flow rate affects the composition of CO gas. The greater the air flow rate, the CO gas composition tends to decrease. The decrease in CO gas content is caused by the greater the air rate, the greater the rate of air entering during the co-gasification process. The more oxygen, the reaction tends to produce CO_2 gas (Zhang et al., 2020). Zhang et al., (2020) explained that the excess oxygen in the co-gasification process will also produce CO_2 gas through the CO gas combustion reaction, thereby reducing the composition of CO gas.

The independent variable of air flow rate affects the amount of H_2 composition resulting from co-gasification. The greater the air flow rate, the H_2 composition tends to increase. This condition is due to the fact that the greater the air that enters the process, the more it will tend to increase the rate of combustion so that the raw material will more

Table 2. Composition of CO gas as a result of co-gasification on the raw material mass composition variable and air flow rate.

Mass Composition (%)			Composition of CO (%) Air Flowrates (L/minutes)			
Compost	Coffee husk	Coal	10	15	20	25
0	100	0	19.92	19.29	18.05	17.36
0	75	25	21.44	21.10	20.28	18.02
0	50	50	20.31	19.69	18.68	17.78
0	25	75	18.90	18.58	17.09	16.70
0	0	100	15.65	14.29	13.87	12.37
50	50	0	16.34	16.22	14.29	15.03
37.5	37.5	25	18.03	17.94	17.19	15.71
25	25	50	18.41	17.60	17.64	16.47
12.5	12.5	75	17.89	17.69	16.20	15.81

Table 3. Composition of H_2 gas as a result of co-gasification on the raw material mass composition variable and air flow rate.

Mass Composition (%)			Composition of H_2 (%) Air Flowrates (L/minutes)			
Compost	Coffee husk	Coal	10	15	20	25
0	100	0	3.12	3.40	4.43	6.27
0	75	25	3.57	3.94	6.89	7.22
0	50	50	3.40	3.69	5.86	6.72
0	25	75	2.38	2.50	3.12	3.65
0	0	100	1.31	1.85	2.38	3.03
50	50	0	1.68	2.62	3.12	3.20
37.5	37.5	25	2.21	3.53	4.43	5.29
25	25	50	2.58	3.40	5.58	6.03
12.5	12.5	75	1.93	2.75	3.77	3.81

easily go through the drying process. The faster the drying process, the greater the water vapor so that it can accelerate the steam-carbon reaction and water-gas shift reaction. A lot of water vapor that evaporates will increase the composition of H_2 because most of the hydrogen gas is produced from reactions involving water vapor. Water vapor is also obtained from the incoming air during the co-gasification process. The air used as a gasification agent has a water content (humidity). The greater the air flow rate, the greater the amount of water vapor that is included in the gasification process so that the H_2 gas content will be even greater.

The gas composition of CO and H_2 is also influenced by the variable mass ratio of raw materials. Samples with a large percentage of coffee husks tend to have higher CO and H_2 gas compositions. This is because the area for the reaction to form CO and H_2 is getting bigger. The difference in the area of the reaction area is due to the large difference in the density of the raw materials. The smaller the density, the more the raw material will fill the gasification space so that it will expand the contact area. The wider the contact area will increase the heating rate (Sudarmanta & Kadarisman, 2010). Another reason is that coffee husk has a higher O element content than coal so that it can accelerate the reaction process for the formation of CO gas (Siahaan, 2018).

Syngas resulting from the co-gasification process with a large percentage of coffee husks tends to have a greater syngas composition because coffee

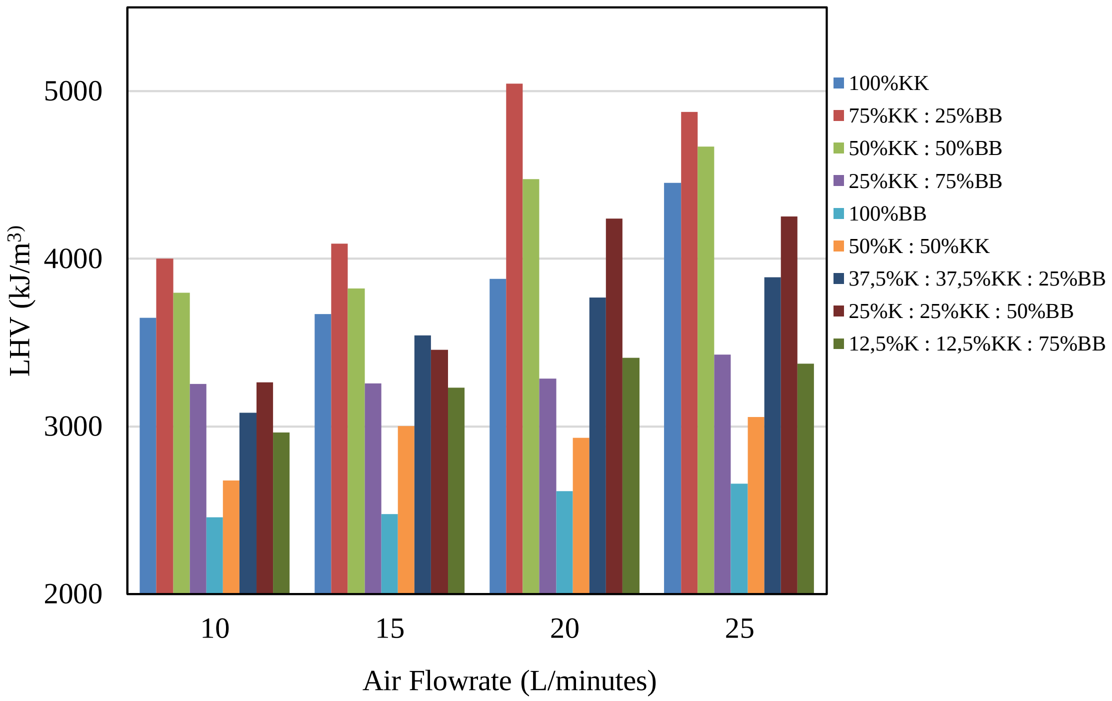


Figure 2. LHV syngas as a result of co-gasification on the raw material mass composition variable and air flow rate.

husks have a high volatile matter value. Volatile substances are a very important parameter because in part of the gasification, sufficient residual energy is still used to convert volatile substances outside of energy to evaporate water from biomass (Myzhar & Sutjahjo, 2019). According to Zhang et al., (2020) the volatiles contained in gasification raw materials can be converted into H_2, CO, CH_4, H_2O, CO_2, and condensed vapor (tar). High volatile matter values can increase the reaction between volatile matter and CO_2 gas (Siahaan, 2018).

Lower Heating Value (LHV)

The syngas produced through the co-gasification process has a low calorific value, but can be burned with high efficiency and produces no smoke emissions. In general, the calorific value of syngas is affected by gasification agents. If air is used as a gasification agent, the resulting calorific value will be low. This condition is caused by the dilution of syngas by nitrogen (N_2) contained in the air. However, if the gasification agent is in the form of pure oxygen or water vapor, the resulting calorific value will be even higher. The calorific value of syngas in this study can be seen in Figure 2.

Figure 2 shows that the greater the air flow rate, the greater the LHV of syngas. Likewise, samples with a large coffee husk mass ratio tend to increase the LHV value. The increased air flow rate causes the syngas composition to also increase because the air supply is still below the stoichiometric limit (Effendi et al., 2013). The independent variable of raw material composition also affects the LHV of syngas. The greater the coal composition, the smaller the syngas LHV value will be. This is because coal as a raw material has not been completely gasified. This condition is proven by the large amount of charcoal produced in co-gasification with a large composition of coal.

The calorific value of syngas in this study is comparable to the composition of the syngas (CO and H_2) produced. Lower calorific value of syngas also indicates of less CO_2 conversion (Thiagarajan et al, 2018). According to Martínez et al. (2011) explains that the greater the composition of the syngas produced, the calorific value of the resulting syngas will also be greater. This can happen because the determination of the calorific value is done by calculating. The syngas composition is multiplied by the LHV value of each syngas component (CO and H_2) (Trifiananto, 2015). The molar ratio of H_2/CO can affect the syngas LHV value, the greater the H_2/CO, the greater the syngas LHV value. According to Martínez et al. (2011) states that the value of LHV H_2 is greater than LHV CO so that the greater the composition of H_2, the greater the value of syngas.

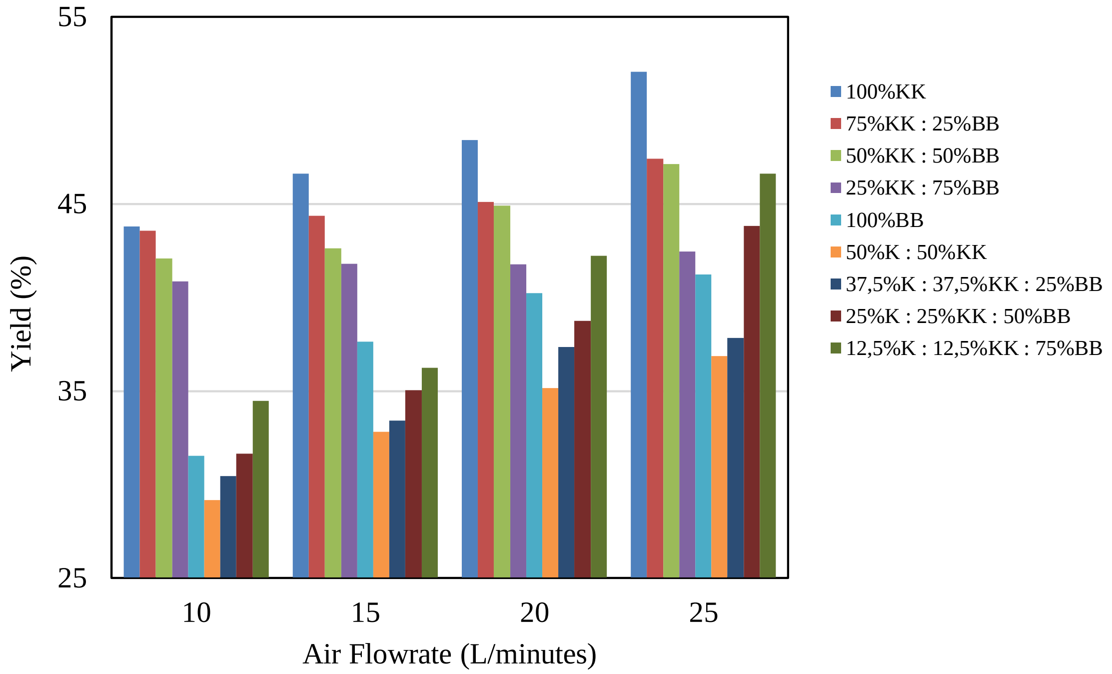


Figure 3. Yield syngas as a result of co-gasification on the raw material mass composition variable and air flow rate.

Yield Syngas

Syngas yield analysis of raw materials in this study in terms of co-gasification by-products. The by-products are tar, charcoal, and ash. The amount of by-products produced varies in each type of gasification reactor (Siahaan, 2018). Syngas yields on raw materials involve by-products in the form of tar, charcoal and ash. Determination of syngas yield is calculated using the equation by dividing the amount of syngas by the raw material. Syngas yield results for raw materials in this study can be seen in Figure 3.

Based on Figure 3, the greater the air flow rate, the syngas yield tends to increase. The addition of oxygen in the air in the co-gasification process causes a greater yield of syngas. This is because the greater the oxygen, the faster the raw material combustion will be so that more syngas is produced. The syngas yield will be smaller as the coal composition increases. This is because raw materials with a large composition of coal will be converted more into by-products in the form of charcoal and ash.

CONCLUSION

The co-gasification process is influenced by the composition of the raw materials and the flow rate of air as the gasification medium. From this study it can be concluded that the greater the composition of the coffee husk, the LHV syngas value will increase. The addition of compost as a raw material for co-gasification lowers the LHV value and produces syngas. the greater the air flow rate, the higher the LHV value and syngas yield.

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