Air Fuel Ratio (AFR) and Temperature's Effects on Syngas Composition and Calorific Value Using a Coconut Shell Downdraft Gasifier

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Abstract. Biomass is an environmentally friendly alternative energy due to its sulphur-free, carbon-neutral, and the abundant availability. Coconut Shell is a type of The calorific value of biomass waste, which is suitable for use as a raw material in the gasification process, is 20890 kcal/kg. Gasification is a process that uses restricted air, 20% to 40% of air stoichiometry, to burn solid fuels and produce syngas (CO, CH4, and H2). Gasifiers are categorized as updraft, downdraft, or cross-flow based on the direction of airflow. .The type downdraft gasifier produce lower tar content than type updraft gasifier. This research was carried out gasification of biomass with Using a downdraft gasifier with coal as a stabilizer, the aim of this research is to ascertain the impact of temperature and AFR on the calorific value and composition of syngas.The variations of air fuel ratio were 0.79, 068, and 1.22. The temperature variations used were the temperature range in the reduction process, that was 600ºC-1000ºC. As a result, the calorific value drops as a result of the decrease in the percentage of CO, H2, and CH4 brought on by the increase in AFR. Only the percentages of H2 and CO 2 grow in the temperature range of 800ºC-1000ºC, whereas the percentages of CO, H2, and CH4 increase in the 600ºC-800ºC range. Syngas's calorific value rises as temperature rises. By using coal in the gasification pro Syngas's calorific value rises as temperature rises. By using coal in the gasification process, stable combustion temperatures within the gasifier may be maintained. Additionally, more syngas can be produced, which increases the amount of CO, CH4, and H2, increasing the calorific value. The research's optimal working parameters were achieved with coal acting as a stabilizer, at an AFR of 0.79 and a temperature of 800ºC. 40.18% of CO, 19.36% of H2, 12.38% of CH4, and 11.4003 MJ/m3 of low heating value (LHV) were found to be the percentage of syngas.

Keywords: Gasification; Syngas; Downdraft Gasifier; Coconut Shell; Caloric value.

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1. Introduction

The International Energy Agency (IEA) predicts a 45% increase in global energy demand by 2030, with an average annual increase of 1.6%. Currently, approximately 80% of the world's energy is derived from fossil fuels, leading to price volatility and supply insecurity]9]. Moreover, the combustion of fossil fuels releases pollutants such as CO2, SOx, and NOx, contributing to acid rain and greenhouse gas emissions, exacerbating global climate change.

96% of Indonesia's energy consumption is still derived from fossil fuels, with 48% coming from oil, 18% from gas, and 30% from coal. The research and use of alternative energy sources must be accelerated in order to address this. A National Energy Policy, which prioritizes the adoption of new renewable energy (EBT) sources like solar, wind, water, and biomass, has the support of the National Energy Council and Commission VII of the House of Representatives. It aims to manage and supply the nation's energy resources until 2050. With these actions, 21% of the country's energy needs will be sustainably met.

Biomass originating from forests, agriculture, and the livestock industry has the capacity to reduce emissions and balance energy consumption [13]. Because it is carbon neutral, free of sulfur, and readily available, biomass is an environmentally benign alternative energy source [9]. All biologically produced materials and living things on Earth that obtain their energy from plant sources [14], such as wood from forests, industrial, agricultural, and forestry wastes, as well as human or animal wastes, are collectively referred to as biomass. Furthermore, biomass is a renewable carbon source that may be converted into gas, liquid, or solid fuel [1]. Numerous thermochemical (combustion, gasification, and pyrolysis), biological (anaerobic digestion and fermentation), and chemical (esterification) processes can result in the production of biomass energy. Gasification [4] of biomass has garnered the most attention among these because to its superior efficiency when compared to pyrolysis and combustion. Traditionally, industrial operations have used biomass as a source of heat and energy through burning. The efficiency of direct combustion of biomass to generate energy is quite poor, ranging from 20% to 40%. Biomass is converted to bio-oil through pyrolysis when oxygen (O2) is not present. The implementation of biomass pyrolysis technology has been restricted due to its limited applicability and challenges in the downstream processing of bio-oil.

The coconut shell is a part of the coconut fruit with a biological function to protect the fruit's kernel, and it is situated inside the husk with a thickness ranging from 2-6 mm. Historically, coconut fruit has primarily been utilized for its flesh in the production of coconut milk, copra, and oil [7]. In contrast, coconut shells [9] have typically been incinerated to yield activated charcoal. However, further exploration of their utilization is essential to prevent environmental contamination and to explore their potential as an alternative energy source for both communities and industries.

Coconut shells are classified as hardwood, with a moisture content of approximately 6-9% (calculated on a dry weight basis). The chemical composition of coconut shells can be seen in Table 1.

Table 1. The elemental composition of coconut shells.

Component	Percentage (%)
Cellulose	26.6
Hemicellulose	27.7
Lignin	29.4
Ash	0.6
Extractive component	4.2
Uronate Anhydrate	3.5
Nitrogen	0.1
Water	8.0

Coconut production, particularly in Lampung Province, exhibits significant potential, as evident in the production data from the last 5 years presented in Table 2.

Table 2. Coconut Production in Provinsi Lampung, 2018 – 2022.

Year	2018	2019	2020	2021	2022
Production (Ton)	86,900	83,400	83,400	81,900	78,319

Table 3. Results of Ultimate, Proximate, and Lower Heating Value (LHV) Testing for Coconut Shells.

Component	Ultimate Analysis (%w)	Proximate Analysis (%w)	Calorific Value of Coconut Shell (KJ/kg)
Carbon (C)	47.89	-	-
Hydrogen (H)	6.09	-	-
Oxygen (O)	45.75	-	-
Nitrogen (N)	0.22	-	-
Sulphur (S)	0.05	-	-
Volatile Matter	-	68.82	-
Moisture	-	6.51	-
Ash	-	.56	-
Fixed Carbon	-	17.11	-
Low Heating Value			20890

Gasification is the process of employing restricted air, between 20% and 40% of air stoichiometry, to burn solid fuels and produce syngas (CO, CO2, CH4, and H2) [66]. Moreover, it can be used straight as fuel, producing syngas that can be utilized in a gas turbine to generate electricity together with heat and steam. The overabundance of gasification can enhance the biomass's energy usage efficiency, primarily in the production of electricity. Combustion of syngas is a process that is more easily controlled so as to lower the production of harmful emissions, production efficiency power that result is higher with combustion of syngas in the gas turbine and steam–gas cycle. Heat loss at lower gasification process and energy production is better than combustion biogas.

The gasifier, a type of gasification reactor, is where the gasification process takes place [6]. Gasifiers are categorized as updraft, downdraft [10, 11], or crossflow based on the direction of airflow. The downdraft gasification method is the most straightforward and capable of producing gas with a respectable quality among the various types of gasification procedures. gasifier with a downdraft that produces less tar than an updraft. This is because the partial oxidation process, which allows the tar content to be broken down into lighter compounds, is made possible by the tar content results carried along the pyrolysis gas. In this study, a downdraft gasifier will be utilized, with the gasses being released from the region underneath the reactor and the combustion air entering from either the top or side of the combustion zone.

The composition of raw materials, gasifier design, température, high static bed, fluidization velocity, equivalency ratio, gasifying agent, catalysts, and other operating prameters all affect the quality of the syngas produced (composition production of CO, H2, CO2, and CH4 and energy content) and the gasification process's performance (yield gas). Gasification of biomass using coconut shell as a raw material was used in this study. By employing a downdraft gasifier with coal as a stabilizer, this study aims to ascertain the impact of temperature and AFR on the calorific value and composition of syngas [2].

2. Methodology

Coconut shell was the source of the raw materials employed in this study. The first step involves size reduction of raw material to particles ranging from 0.5- 5.0 cm. After being dried in the sun to remove moisture until the samples reached a consistent weight, they were placed in storage pending additional examination and testing. Both proximal and ultimate analysis are used to determine the wood's chemical makeup. The moisture content, ash content, volatile matter, and fixed carbon were measured using TGA-701.The amount of carbon, nitrogen, hydrogen, sulfur, and oxygen in the raw material was ascertained using CHNS TruSpace. Using a bomb calorimeter, the raw materials' calorific value was also examined.

The tools utilized in the study consist of the Vulcan Downdraft Gasifier, TGA, Ultimate, Bomb Calorimeter, Analytical Balance, butane lighters, Digital Thermometer Gun, Digital Hygro Meter, Gas Chromatography.

A raw material, gasifier reactor, cyclones, coolers, tar filter, blower, gas engine generators, and generator control panel are the typical components of the Vulcan Downdraft Gasifier used in this study. Along with detecting biomass consumption, this gadget also has temperature and pressure control mechanisms [3].

To control the flow rate of biomass into a gasification reactor, a screw and a stirrer were added to about 100 kg of coconut shells that were stored. Producer gas, a byproduct of gasification, is mostly composed of inflammable gases (N2 and CO2) and combustible gases (CO, H2, and CH4). The characteristics of the gasification process, biomass content, particle form, and biomass all have a significant impact on the gas's composition. A cyclone function that removes coarse particles from the syngas is also present in the gasification reactor. Syngas will be coming out of the gasifier's bottom. Next, before the syngas depart through the stack gas, the tar will be removed using the Tar Filter function. The motor generator unit will receive syngas if the stack gas valve is closed, which will power a gas turbine that turns the generator to generate energy. However, the syngas must first run through a filter containing rice husks in order to remove dust and soot from the syngas, as this could negatively impact the gas turbine's performance [8].

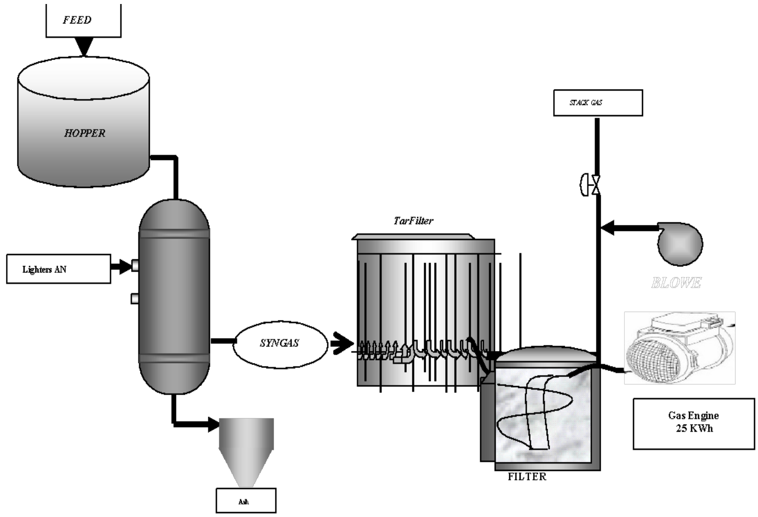

Fig. 1. Scheme of downdraft gasifier equipment.

3. Result and Discussion

3.1. The Impact of Temperature and AFR on the CO Percentage in Syngas

In this study, the amount of carbon monoxide (CO) in the syngas decreased as AFR increased. On Fig. 2 can be seen that on 0.79 AFR and temperature of 600oC, the CO content as much as 31.21% was decreasing to 29.17% at AFR 0.86 and 26.64% on the AFR of 1.22. Decrease of the CO content is the same in every AFR at temperature range 700ºC-1000ºC. While the decreasing in CO with the increasing of AFR caused partial combustion of different gaseous components which resulted a large increase in CO2 concentration (Ghani et al, 2009). The amount of CO in the syngas is also impacted by the rising temperature throughout the gasification process. At 0.79 AFR and temperature reduction in the range of 600ºC - 800ºC increasing the CO content by 6.4 - 8.6%, but the content of CO will decrease if the temperature was more than 800ºC up to 0.8-1.2%. At 0.86 AFR and temperature reduction in the range of 600ºC - 800ºC increasing the CO content by 5.6-6.7%, but the content of CO will decrease if the temperature was more than 800ºC up to 1.9-2.8%. At 1.22 AFR and temperature reduction in the range of 600ºC - 800ºC increasing the CO content by 4.5-5.2%, but the content of CO will decrease if the temperature was more than 800ºC up to 2.2-2.9%. The CO content was mainly determined by the bourdard reaction ($CO2 + C \rightarrow 2CO$). Higher temperature was not favorable for CO production, thus the content of CO decreased and the CO2 content will increase.

The second study was conducted by using coal as a stabilizer in the gasification process with a variation of AFR and temperature are the same as the first study. In Fig. 3 can be seen using coal effect on the CO content in the syngas that although gasification temperature was more 800oC [5], Despite not being a particularly noticeable rise, the CO content produced did increase. At 0.79 AFR, temperature 600ºC-800ºC CO content increased to 6.2-11.9%, while in the temperature range of 800ºC-1000ºC CO content continues to increase but only by 0.7 - 0.9%. At 0.86 AFR, temperature 600ºC-800ºC CO content increased to 5.4-10.0%, while in the temperature range of 800ºC-1000ºC CO content continues to increase but only by 0.4-0.5%. At 1.22 AFR, temperature 600ºC-800ºC CO content increased to 6.7-10.4%, while in the temperature range of 800ºC-1000ºC CO content continues to increase but only by 0.2-0.3%. This is due to the fact that using coal helps maintain the gasifier's internal temperature, which promotes the best possible CO creation reaction during the reduction process.

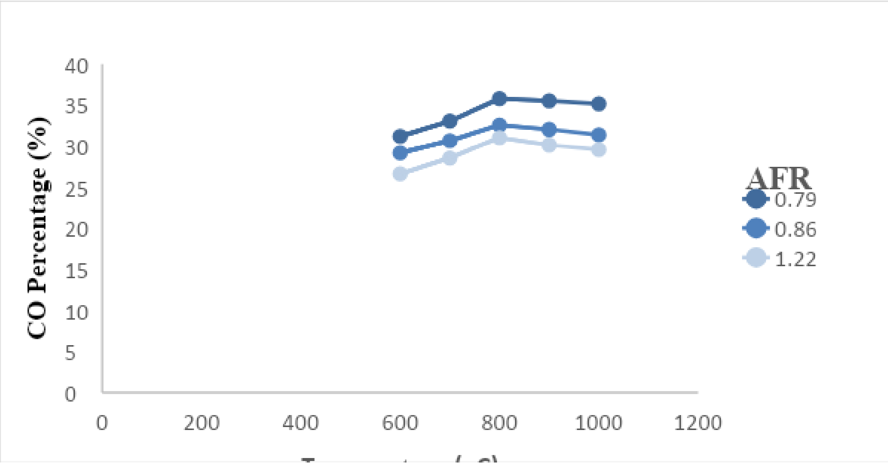

Fig. 2. The temperature and AFR effects on CO% in the absence of coal.

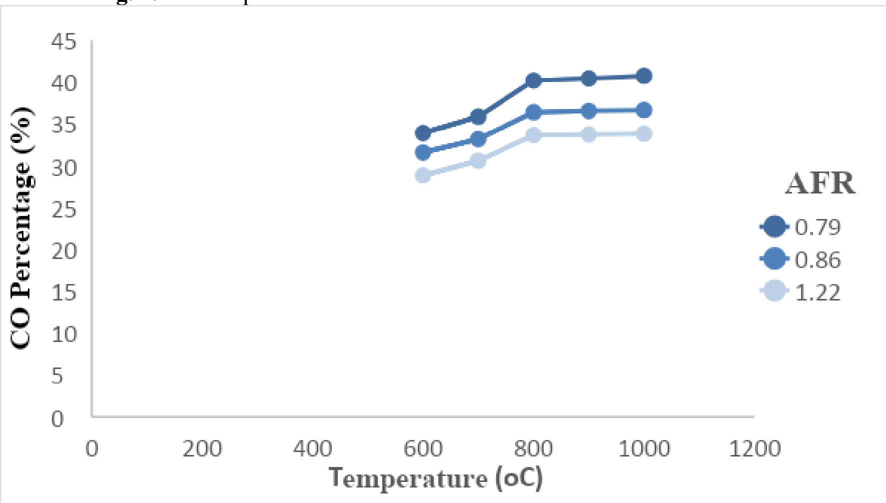

Fig. 3. The impact of temperature and AFR on CO% when utilizing coal.

At 0.79 AFR CO content increased significantly at temperatures of 700ºC - 800ºC in the amount 8.59% (without coal) and 11,98% (with coal). The best conditions in this research was on 0.79 AFR and the temperature of 800ºC, on the condition CO content obtained by 40,18% in research with coal as a stabilizer while on this research without coal amounted to only 35.77%.

3.2. Temperature and AFR's Impact on CO2 Percentage in Syngas

This investigation also observes the carbon monoxide (CO2) level in syngas. Fig. 4. and Fig. 5 demonstrate how the CO2 concentration rose as AFR climbed, reaching 0.79 AFR. At 600 oC, the CO content increased by 28.89%, 30.72% at AFR 0.86, and 33.81% at 1.22 AFR. The syngas's CO2 content will rise when the AFR increases during the gasification process and approaches the AFR stoichiometric (Diaz et al, 2014). A decrease in concentration of CO2 indicated a better gasification efficiency (Zainal et al, 2002). Research without of coal as stabilizer at 0.79 AFR and Temperature 600ºC-800ºC, CO2 content decreased from 4.3 – 6.4%. At 0.86 AFR and temperature reduction in the range 600ºC - 800ºC, CO2 content decreased from 4.1 – 6.0%. At 1.22 AFR and temperature reduction in the range 600ºC - 800ºC, CO2 content decreased from 2.5 – 4.6%. The CO2 content will increase if the temperature was more than 800ºC. The conversion of CO2 into CO happened at a temperature of more than 500ºC during gasification; however, at temperatures higher than 800ºC, the concentration of CO started to fall, increasing the CO2 content. According to Chen et al. (2012), rising temperatures caused the CO2 mole percentage to rise while the CO mole % fell. These trends occurred because higher temperature shifts the equilibrium of the endothermic reaction (e.g. CO2 + H2 → CO + H2O) to the products and that of the exothermic reaction (e.g. CO + H2O → CO2 + H2) to the reactants.

In Fig. 5, It can be seen the influence of coal utilization as stabilizer towards the CO2 content, eventhough the temperature was more than 800oC, CO2 content kepp decreasing at 0.79 from 1.8-2.5%, at 0.86 from 1.7-2.1%, and at 1.22 from 1.6-1.9% along with the increasing of CO content in the syngas. The trend of CO2 could be correlated with trend opposite for CO (Ramanan et al, 2008).

At 0.79 AFR CO2 content decreased significantly at temperatures of 700ºC - 800ºC in the amount of 6.01% (without coal) and 7.63% (with coal). The best optimum conditions in this study was on 0.79 AFR and the temperature of 800ºC, in these conditions the CO2 content obtained was 23.82% on research with coal as a stabilizer while on this research without coal amounted to 26.37%.

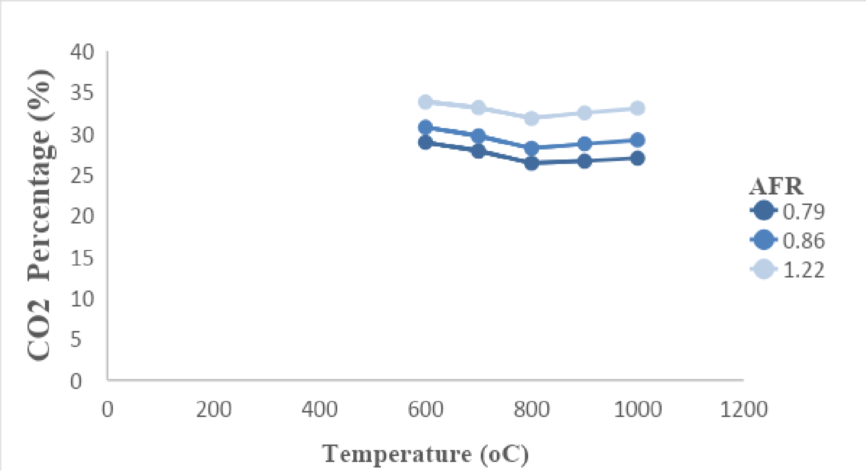

Fig. 4. Temperature and AFR's influence on CO2 without coal use.

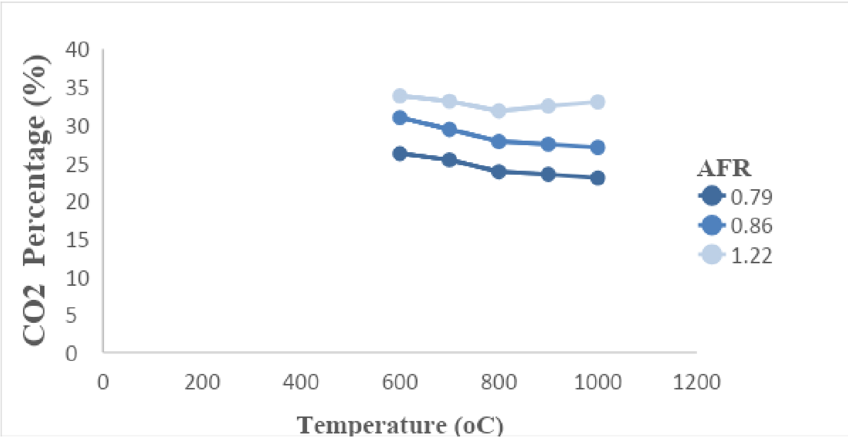

Fig. 5. AFR and temperature's effects on CO2 percentage when utilizing coal.

3.3. The Effect of AFR and Temperature on CO_2 Percentage in The Syngas

The result of hydrogen in the syngas from this study was observed by increasing AFR so the content of H2 will decrease. A Similar trend is reported by other Researchers like [12]. In Fig. 6 and 1 can be seen that with the increasing of AFR, then the H2 content decreased the 0.79 AFR and at temperature of 600oC the CO content increased by 18.04%, 17.63% at AFR 0.86 and 16.69% at 1.22 AFR. It was occured because when approaching 1.5 AFR (AFR stoichiometric) then H2 will be converted into steam (H2O) so that the content of H2 in the syngas will be reduced.

In Fig. 6, it can be seen the effect of temperature on the content of H2 with a temperature range of 600ºC - 1000ºC. H2 content also increased in the amount of 1.2-3.3% at 0.79 AFR, 1.7-3.2% at 0.86 AFR, and 0.6-1.6% at 1.22 AFR. This is due to the increase of temperature which stimulated the steam-carbon reaction (C + H2O → CO

+ H2). However, H2 could also be preferentially combusted if temperature became very high. Claimed that hydrogen will rise as temperature rises and progressively fall at high temperatures (over 1000ºC) [12]. When coal was used as a stabilizer in this investigation, the H2 content produced was greater than in previous studies that used coal at temperatures between 600 and 1000 degrees Celsius and an AFR of 0.79. At 0.86 AFR, H2 concentration increased from 0.5-0.8%, and at 1.22 AFR, it climbed from 0.3-0.4%. A greater H2 concentration will result in less H2O developing in the syngas because too much H2O causes the hydrocarbons to fracture and the reforming process to speed up.

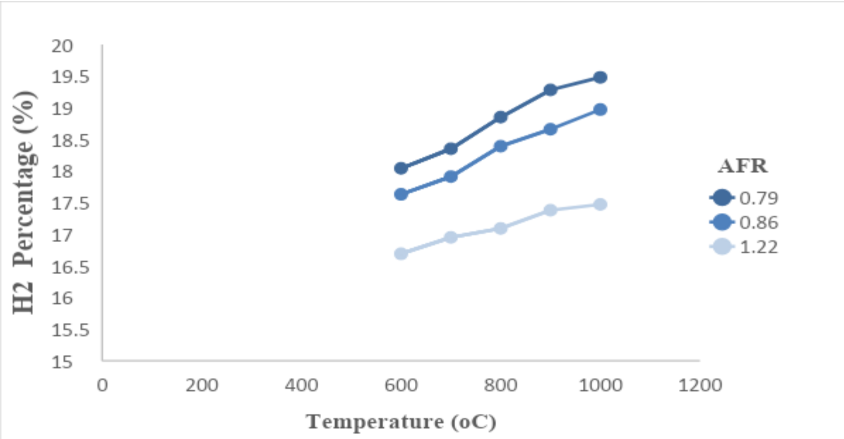

Fig. 6. Temperature and AFR's influence on H2 percentage without coal use.

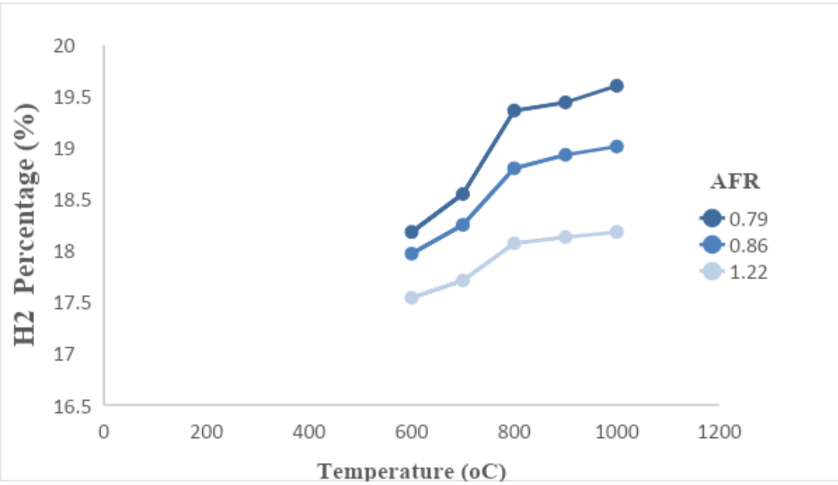

Fig. 7. The impact of temperature and AFR on %H2 using coal.

On the 0.79 AFR, H2 content increased significantly at temperatures of 700ºC - 800ºC amounting 3.35% (without coal) and 5.07% (with coal). So that the optimum conditions in this study was on 0.79 AFR and the temperature of 800ºC, in these conditions, H2 content obtained was 19.36% on research with coal as a stabilizer while on research without coal by 18.85%.

3.4. The Effect of AFR and Temperature on CO_2 Percentage in The Syngas

The result of methane gas (CH4) in the syngas of this study was observed by increasing AFR so the content of CH4 will decrease. A Similar trend is reported by other researchers like Turn et al. (1998). In Fig. 8 and Fig. 9 can be seen that with the increasing of AFR, then the CH4 content decreased the 0.79 AFR and at temperature of 600oC the CH4 content increased by 11.35 %, 11.23 % at AFR 0.86 and 11.02% at 1.22 AFR. inferred that increasing the AFR results in a decrease in concentrations of methane and other light hydrocarbons, which have relatively high heating values. The model results validate the claim that CH4 concentration decreases with increasing AFR. The AFR was increased, the production of CO2 increased. Additionally, the decreased number of carbonaceous materials remaining for gasification reactions may result in the decreased production of hydrocarbon gases such as CO, CH4 and C2Hn.

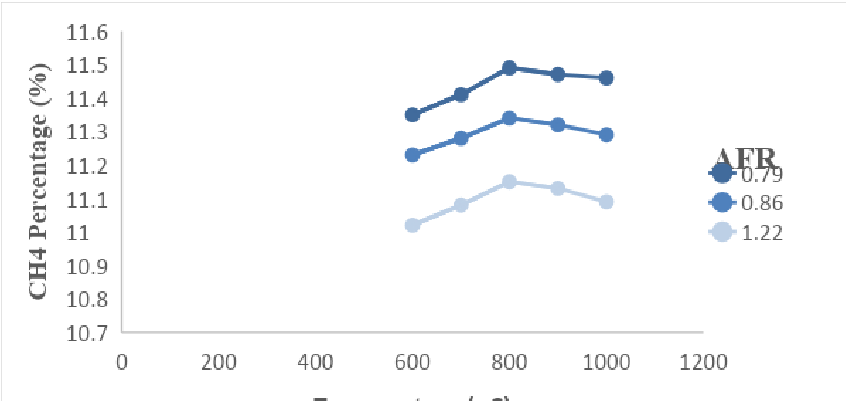

Fig. 8. The temperature and AFR effects on CH4 percentage without coal use.

On 0.79 AFR and temperature reduction in the range of 600ºC - 800ºC increasing the CO content by 0.7-0.9%, but the content of CH4 will decrease if the temperature was more than 800ºC up to 0.1-0.2%. At the 0.86 AFR and the temperature reduction range of 600ºC-800ºC, the CH4 content increased by 0.6 – 0.7%, but the CH4 content will decrease by 0.2-0.4% when the temperature was more than 800oC. At the 1.22AFR and the temperature reduction range of 600ºC-800ºC, the CH4 content increased by 0.7-0.8%, but the CH4 content will decrease by 0.2-0.5% when the temperature was more than 800oC Based on Le Chatelier's principle, it is understood that higher reaction temperatures favor the reactants in exothermic reactions while they favor the products in endothermic reactions. Consequently, this idea was confirmed by the methane reforming reaction's endothermic reactions (C + 2H2 → CH4). High temperature methane produced in the gasifier performed endothermic reactions with the water vapor that had previously generated, converting it into CO, CO2, and H2. As a result, the CH4 output dropped as temperatures rose. The graphic illustrates how the proportions of hydrogen and carbon monoxide rise with temperature while the proportions of carbon dioxide and methane drop. This can be attributed to the slowing down of the methanizing reactions and the increased likelihood of water gas reactions (C + H2O → CO + H2).

The second study was conducted by using coal as a stabilizer in the gasification process with a variation of AFR and temperature are the same as the first study. In the Fig. 9, it can be seen the effect of using coal on CH4 content in the syngas that although gasification temperature was more than 800oC, CH4 content generated still increased, although the increase is not very significant. At 0.79 AFR, temperature of 600ºC - 800ºC content of CH4 increased to 0.9-1.6%, while in the temperature range of 800ºC - 100ºC content of CH4 continued to increase but only by 0.4%. At 0.86 AFR, temperature of 600ºC - 800ºC content of CH4 increased to 0.8-1.2%, while in the temperature range of 800ºC-100ºC content of CH4 continued to increase but only by 0.2%. At 1.22 AFR, temperature of 600ºC-800ºC content of CH4 increased to 0.8-1.3%, while in the temperature range of 800ºC-100ºC content of CH4 continued to increase but only by 0.2%. This was due to the fact that using coal could maintain the gasifier's internal temperature and promote the best possible CH4 production reaction throughout the reduction phase. So, the best of conditions in this study was on 0.79 AFR and the temperature of 800ºC, in these conditions, the CH4 content obtained was 12.38% on research with coal as a stabilizer while on the research without coal for 11.49%.

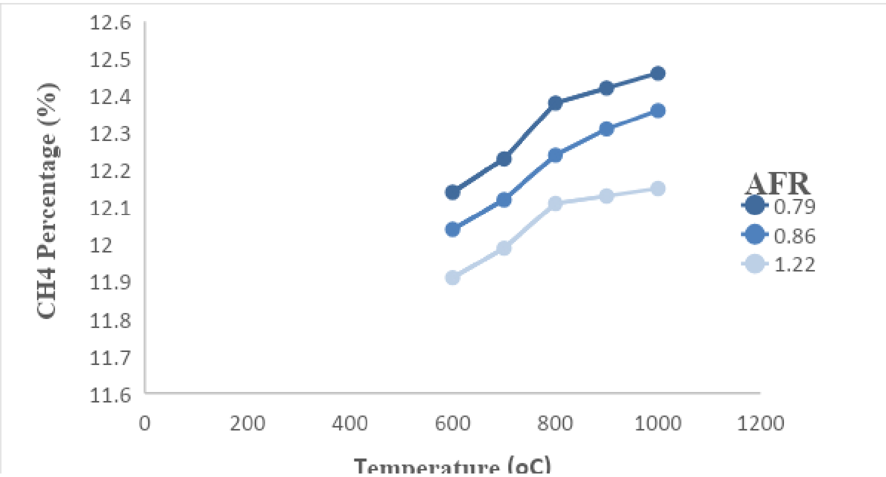

Fig. 9. Temperature and AFR's effects on CH4 percentage when utilizing coal.

3.5. The Effect of AFR and Temperature on CO_2 Percentage in The Syngas

Low heating value is the spesific lower calorific value of a gas component species i.e., CO and CO2. The summation of the lower calorific value of all gas component species (CO, CO2, H2 dan CH4). Fig. 10 and Fig. 11 demonstrate how the value of

LHV syngas decreased as the AFR increased. This is due to an increase in the gasifier's air mass flow rate supply, which will immediately enhance AFR and have an impact on the chemical reaction that forms the syngas content. There will often be a decrease in the amount of syngas (CO, H2, and CH4) when the gasification process necessitates a restricted air supply. The amounts of CO2, N2, and O2 in syngas will rise in tandem with an increase in the mass flow rate of the air supply.

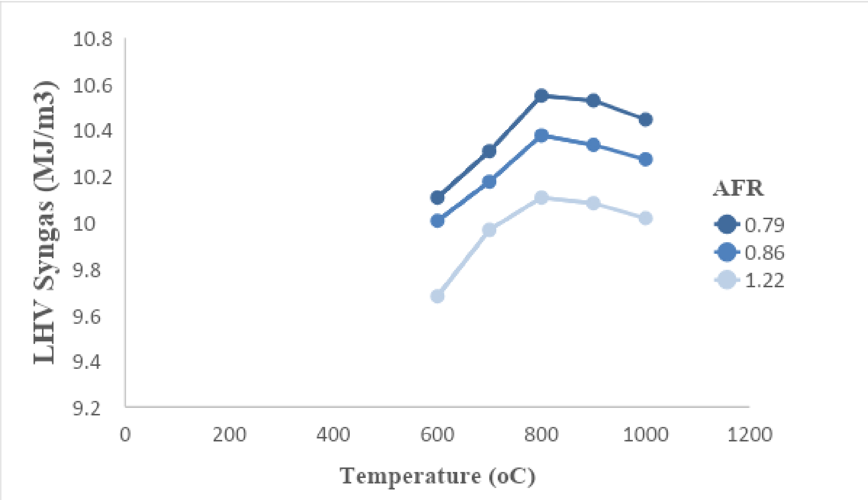

Fig. 10. temperature and AFR's impact on LHV without coal use.

The study found that when coal was not used at temperatures higher than 800ºC, the composition of CO and CH4 in the syngas dropped, resulting in a decrease in LHV. Increased concentrations of CO, H2, and CH4 in the syngas cause a rise in LHV syngas gasifier with higher temperatures in coal-based research. Temperature is thought to be the most crucial element in lowering tar concentration; as temperature rises, more syngas will be produced as a result of the reaction, which will lower tar conversion.

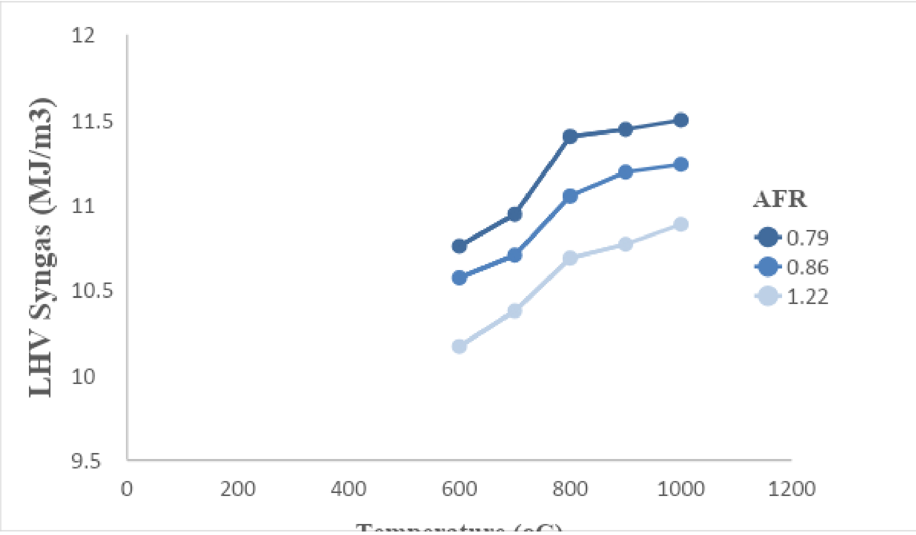

Fig. 11. The impact of temperature and AFR on coal-based LHV.

On the 0.79 ARF, LHV of syngas increased significantly at temperatures of 700ºC-800ºC in the amount of 2.79% (without coal) and 4.84% (with coal). So, the best of conditions in this research was on 0.79 AFR and the temperature of 800ºC, on this condition, LHV of syngas that was obtained by 11.4003 MJ/m3 at research with coal as a stabilizer while on the research without coal amounted to only 10.5482MJ /m3.

4. Conclusion

1. Because of the increase in AFR, the percentage of CO, H2, and CH4 decreases, which causes a drop in the calorific value. The percentages of CO, H2, and CH4 rise between 600 and 800 degrees Celsius, while only the percentages of H2 and CO2 increase between 800 and 1000 degrees Celsius.Syngas's calorific value rises as temperature climbs.
2. Using coal in the gasification process helps keep the gasifier's combustion temperatures constant while producing more syngas, which raises the percentage of CO, CH4, and H2 and raises the calorific value.
3. The research found that the optimal working conditions were achieved with coal used as a stabilizer, an air fuel ratio (AFR) of 0.79, and a temperature of 800ºC. 40,18% of CO, 19.36% of H2, 12.38% of CH4, and 11.4003 MJ/m3 of low heating value were found to be the proportion of syngas.

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