Integrated Coal Gasification Steam Power Plant Simulation Using Cycle Tempo

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***Abstract* -** Coal is a favorite fuel for steam power plant systems and its conversion through the gasification process has several advantages over the direct combustion system. It is also important to note that simulation is an inexpensive method of predicting steam power plant performance and this is the reason it was applied to two configurations of the power plant in this study. The first configuration is a steam power plant system operating utilizing producer gas from coal gasification in the boiler as fuel while the second was directly integrated into the coal gasification system. The aim was to determine the effect of the combustion air in the combustor of boiler on the performance of the power plant systems. Moreover, the ratio of air and fuel was varied and the simulations were conducted using cycle tempo software. The results showed that the first configuration (I) produced a thermal efficiency between 31.6% to 32.4% and electric power of 24.4 to 25 MWe while the second (II) had 16.5% to 16.9% and 23.7 to 24.3 MWe respectively.

Key Word- Integrated, Coal, Gasification, Steam, Power, Plant, Simulation

I. INTRODUCTION

The use of coal as a fuel for steam power generation systems is currently very popular because of its availability and relatively cheap price [1]. The need for electricity in Indonesia has increased by approximately 6% and is reported to be met by coal [2]. Moreover, the power plant system in the country is dominated by a 50% Coal Fired Plant [3]. It is also important to note that global coal-fired power plants are projected to increase by approximately 2.3% per year up to 2035 [4]. It is still dominant about 74% in 2040 [5]. There was also a change in the system of converting coal into energy from direct combustion to the gasification system. This means it is possible to initially predict the operating parameters, power generated, and thermal efficiency through thermodynamic simulation using several software such as the cycle tempo [6].

Several simulations have been conducted for power generation systems in previous studies. For example, Thattai et al [7] simulated the retrofit process of a combined cycle power plant system with a solid oxy-fuel cell and CO_2 captures using a cycle tempo and the results showed that the IGCC was not significantly modified through the process and the efficiency was up to 40%. Thattai et al [8] also compared the application of simulation and experimental methods on the IGCC with a mixture of coal and biomass fuels, and a deviation of approximately 3% was reported. Moreover, Rajev et.al [9] simulated a steam power palnt to investigate energy and exergy of 3x 300 MW steam power plant and the results showed that the first law and the second law of thermodynamic efficiency are 34.35% and 33.64% respectively. Patel et al [10] also simulated a conventional steam power plant fuelled by coal using a cycle tempo it was discovered that the condenser pressure has given most influencing factor for reducing of the first law and the second law of thermodynamic efficiency with the reduction about 0.4%. Another study by Ferreira [11] simulated an MSW-fueled power generation system by comparing the configuration of gas turbine, incinerator, and steam turbine systems with the configuration of gasification, gas turbine, and steam turbine systems. The results showed that the gasification system produced the greatest thermal efficiency. Widodo et al [12] compared the results of the simulation through the cycle tempo and the actual conditions for combined cycle power plant system heat rate at a load of 50% to 100% and the results showed that the difference in heat rate was less than 1%. Another study by Dambrosio et al [13] simulated the integration of biomass gasification with a combined cycle with the water steam turbine replaced by an organic Rankine cycle and the findings indicated that the system is suitable to integrate biomass gasification and combine cycle although its efficiency is low. Moreover, Kumar et al [14] simulated three types of conventional plants which include subcritical, supercritical, and ultra-critical, and the outputs presented that the efficiency for each was 41.40, 42.48, and 43.03% respectively. Pal et al [15] also used a power plant and found that the efficiency is ± 32% and subsequently reduced when excess water was more than 10% while Ahmadi et al [16] conducted a repowering simulation on a power plant utilizing natural gas and reported a maximum thermal efficiency of ± 38%. Khankari et al [17] also simulated a 500 MW power plant by adding a Kalina cycle and utilizing the heat discharged in the condenser, and the results showed an increase in the efficiency by ± 0, 302%. Moreover, Kishore et al [18] used a combined cycle of 150, 200, and 250MW, and found the thermal efficiency to be 40.753, 41.518, and 42.697% respectively, while Hassan Ozgoli [19] integrated biomass gasification into a molten carbonate fuel cell and combine cycle, and showed that 43 MW power generated an electrical efficiency of 71%. Satrio et al [20] simulated a conventional power plant using tree variety of fuel were natural gas, biosolar B50 and MFO and obtained a the highest of thermal efficiency about 31.78% by using B50, while Amirantea et al [21] used a small scale of 45 kWe combined cycle with biomass fuel and showed an electrical efficiency of 18%.

These studies showed that several power plants have been simulated using a cycle tempo but none integrated a steam power plant with the coal gasification system and this is the focus of this study. The other hand of the novelty is comparing performance of steam power plant using producer gas as fuel (configuration I) and direct integrating with coal gasification system (configuration II). The simulation was conducted to determine the effect of the air-fuel ratio of combustor of boiler on the performance of the generating system.

II. METHODOLOGY

Cycle tempo was implemented for the simulation in this study based on the operating parameters presented in Table 1. Some of operation parameters refer to reference [22] and block gasification refers to reference [23]. Moreover, the ratio of the mass air and fuel was varied in the combustor of boiler while the fuel flow rate was kept constant. The simulation was done on two configurations with the first being a steam power plant system fueled with producer gas from coal gasification as shown in Figure 1 while the second was a power plant system directly integrated into a low rank coal gasification system as indicated in Figure 2.

Table 1. Parameters operation used in the steam power plant fueled producer gas

Parameter	Value
Fuel (Producer Gas) Composition	CO 21.25%
	H_2 19.32%
	CH_4 3.15%
	CO_2 10.50%
	N_2 45.79%
Air-Fuel Ratio at Combustor of Boiler	1.5; 1.75; 2; 2.25
Mass Flow of Fuel	14 kg /s
Mass Flow of Steam	29,2 Kg/s
Inlet Pressure of Turbine	89 bar
Pressure of Condenser	0,074 bar
Pressure of The First Extraction	12 bar
Pressure of The Second Extraction	4,9 bar
Pressure of The Third Extraction	0,38 bar

Table 2 Parameters operation used in integrated coal gasification steam power plant

Parameter	Value
Gasification	
Fuel Mass Flow	6.4 kg/s
Air Fuel Ratio	1.5
Ultimate Analysis of low rank coal	
C	57.35%
H_2	4.31%
O_2	17.37%
N_2	0.77%
Steam power plant	

Air-Fuel Ratio at combustor of boiler	1.5; 1.75; 2; 2.25
Mass Flow of Steam	29,2 Kg/s
Inlet Pressure of Turbine	89 bar
Pressure of Condenser	0,074 bar
Pressure of The First Extraction	12 bar
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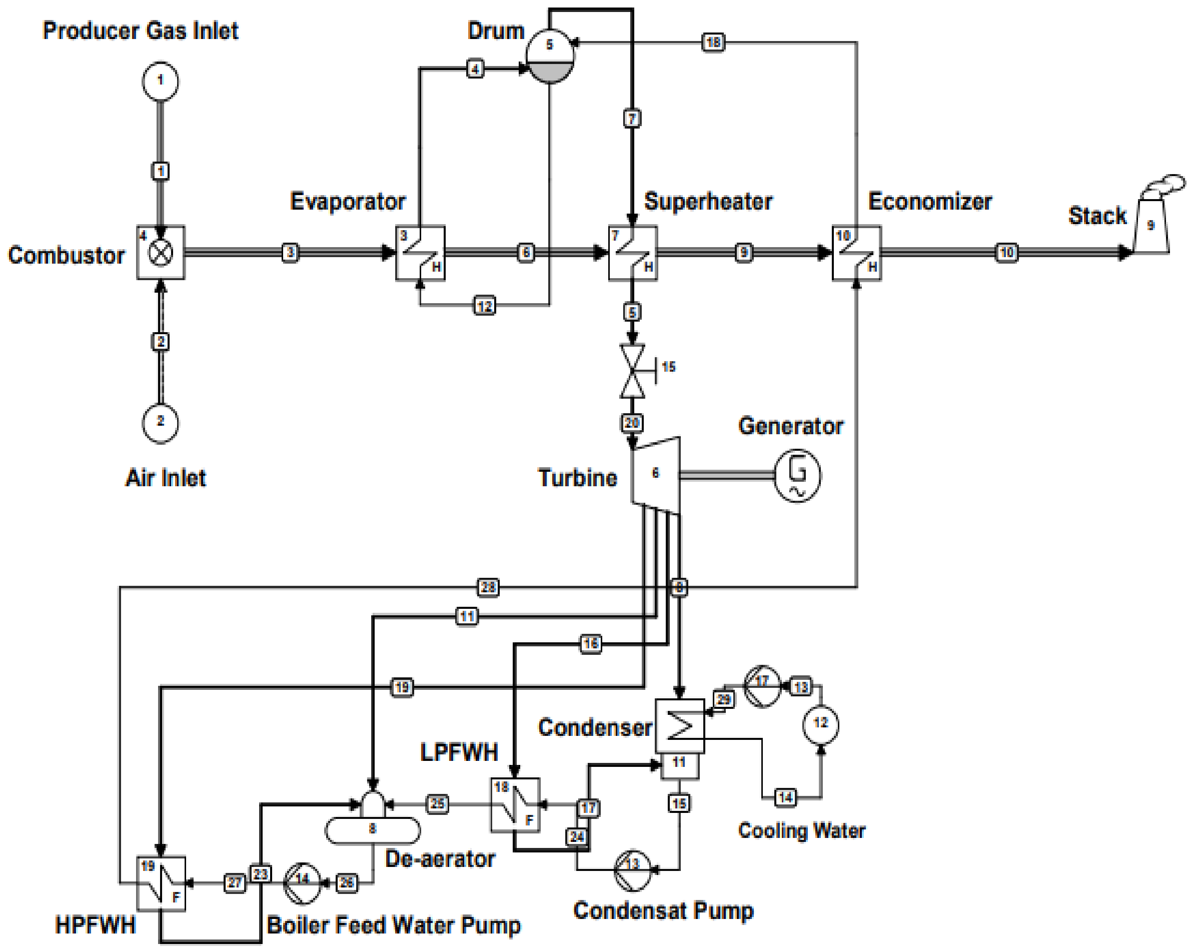

Figure 1. Cycle tempo layout of steam power plant fueled using producer gas (configuration I)

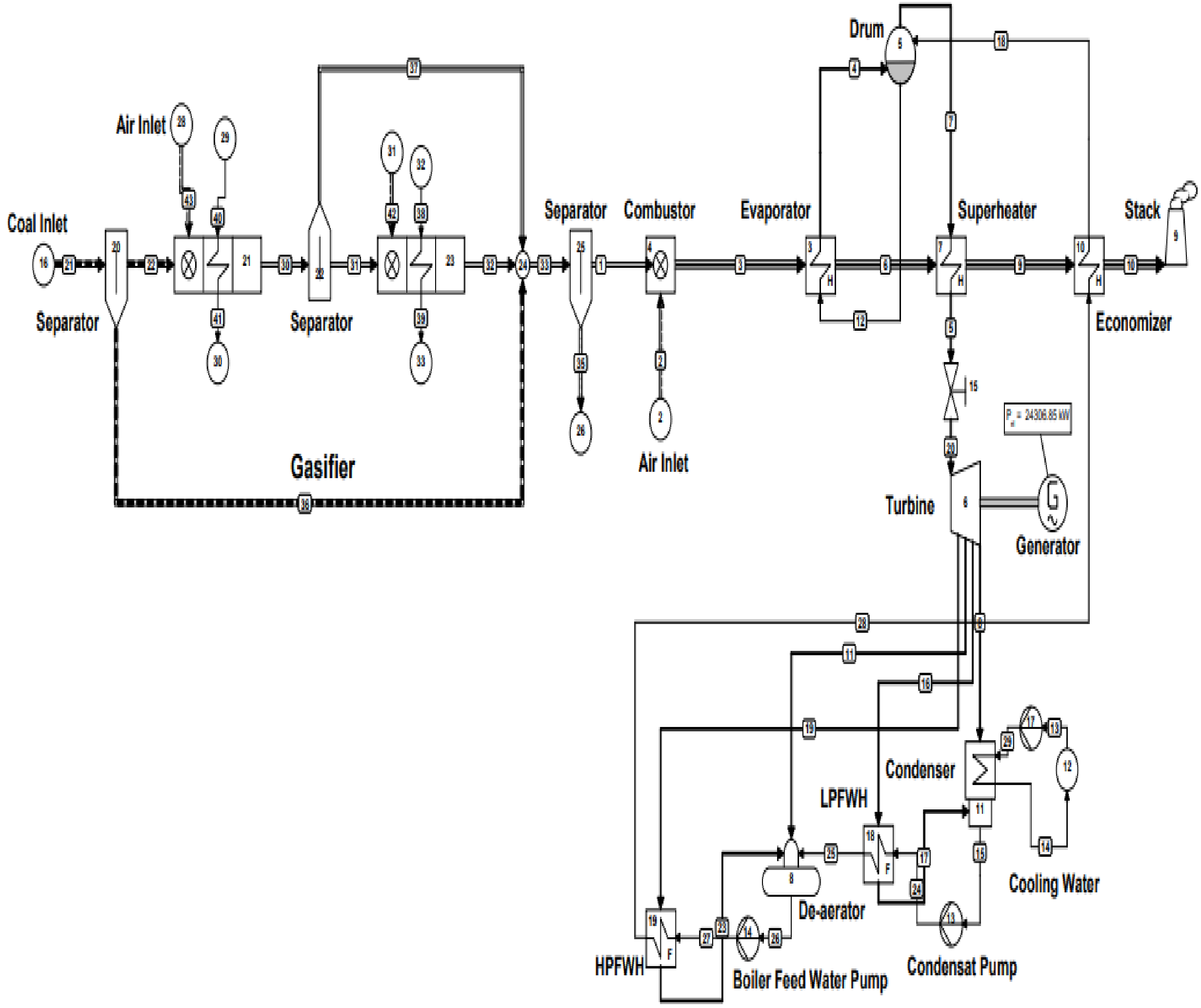

Figure 2. Cycle tempo layout of integrated coal gasification steam power plant (Configuration II)

III. RESULTS AND DISCUSSION

3.1. The correlation of the compering of air and fuel in the combustor of boiler on the combustion temperature.

Figures 3 and 4 show that an increase in the compering air and fuel tends to reduce the temperature of the combustor and this is not much different for both the simulation and experimental reports [24-25]. It was discovered that the temperature reduced from 1707 to 1387^{0}C for configuration 1 and 1851 to 1497^{0}C for configuration 2. Meanwhile, [9; 26] previously reported that the temperature of the furnace can be more than 1500 ^{o}C.

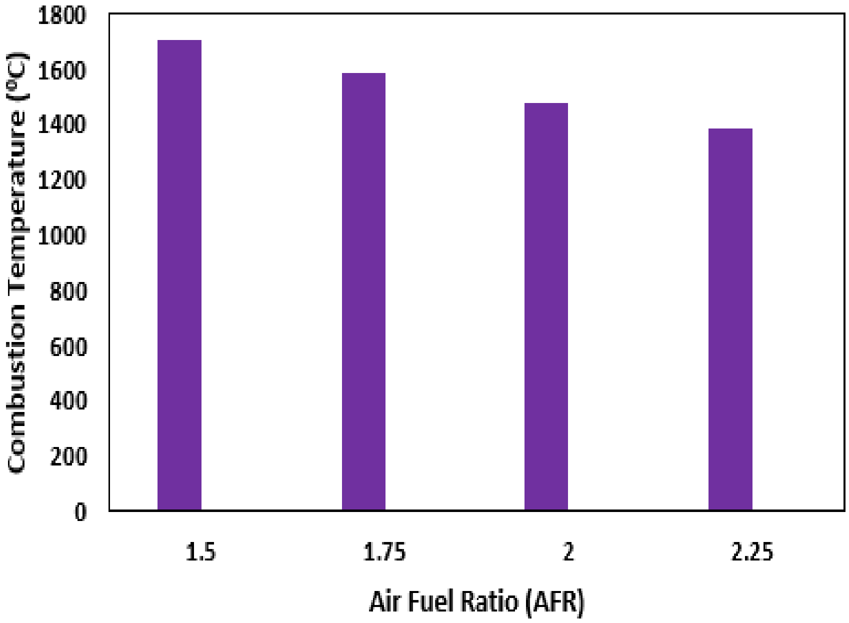

Figure 3. The air fuel ratio vs combustor temperature for configuration I

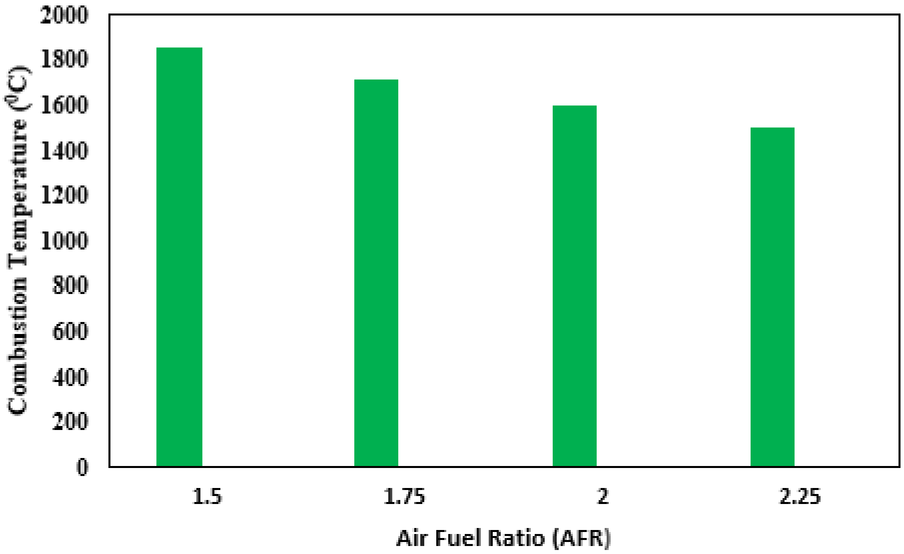

Figure 4. The air fuel ratio vs combustor temperature for configuration II

3.2. The correlation of the compering air and fuel in the combustor of boiler on the temperature of the steam entering the turbine

Figures 5 and 6 show that the enhancement in the compering of air and fuel led to a reduction in the temperature produced in the superheater or the temperature of the steam inlet turbine. This is associated to the change in the phase of water and the raise of water temperature due to the absorption of heat in the boiler This is in line with the decreasing trend observed for the boiler combustor temperature as indicated in Figures 3 and 4, which subsequently reduced the temperature at the inlet turbine for configurations I and II from 409 to 393^0C and 399 to 375^0C respectively. This is similar to the range reported by [26-27].

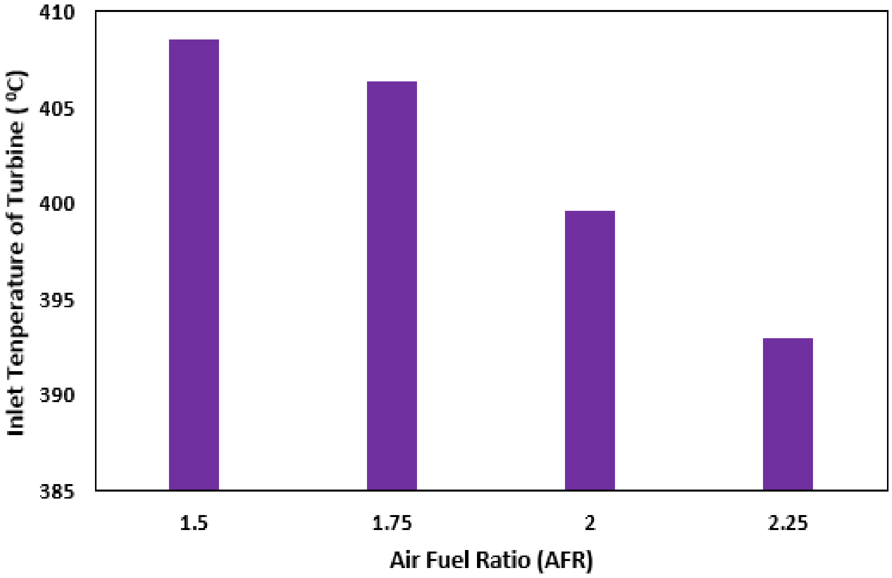

Figure 5. The ratio of air-fuel vs turbine inlet temperature for configuration I

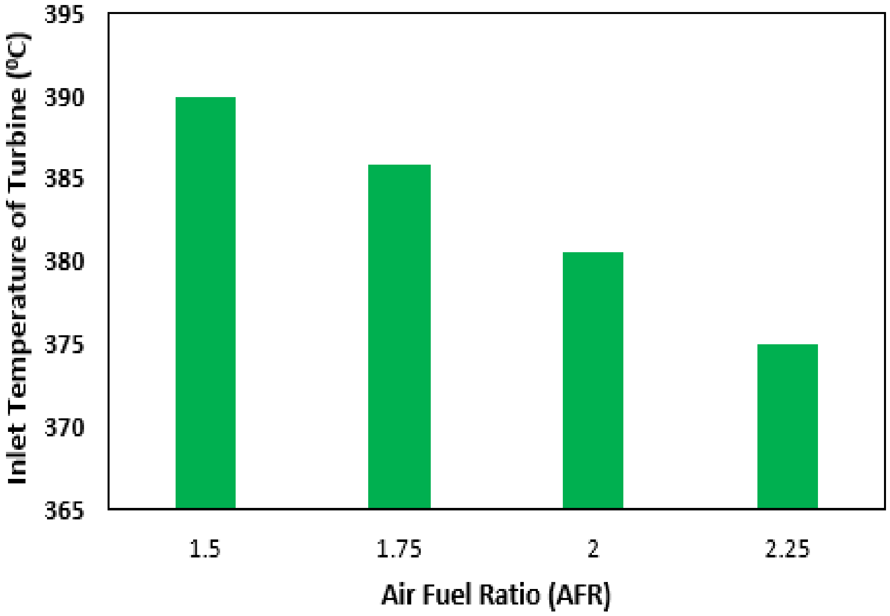

Figure 6. The ratio of air-fuel vs turbine inlet temperature for configuration II

3.3. The correlation of the compering of air and fuel in the combustor of boiler on the power generator

It was discovered from Figures 7 and 8 that an enhancement in the compering of air and fuel led to a reduce in the power generator due to the reduction in the thermal energy of the steam as shown in Figures 5 and 6 and the other hand input fuel which was held constant. The power was observed to have reduced from 25 to 24.4 MWe for configuration I and 24.3 to 23.7 MWe for configuration II.

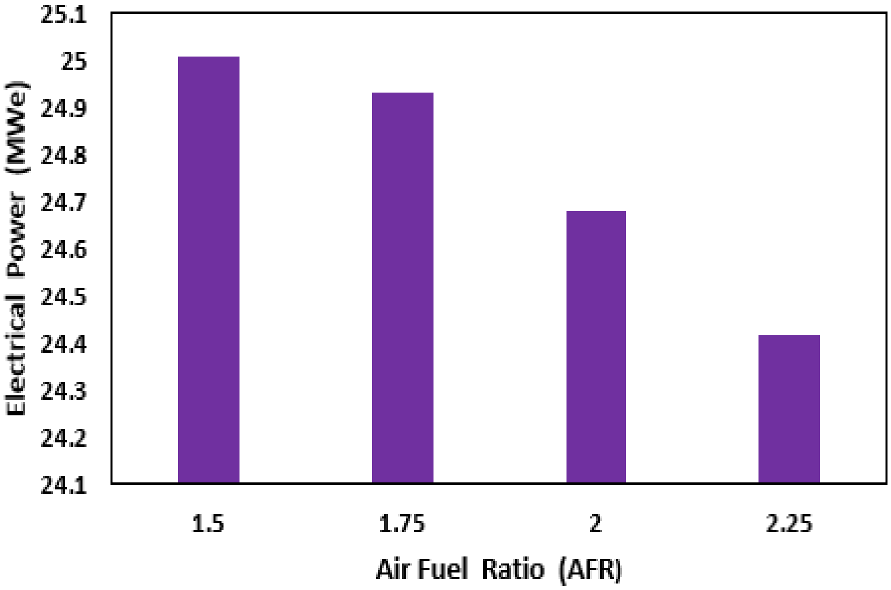

Figure 7. The air-fuel ratio vs power generator for configuration I

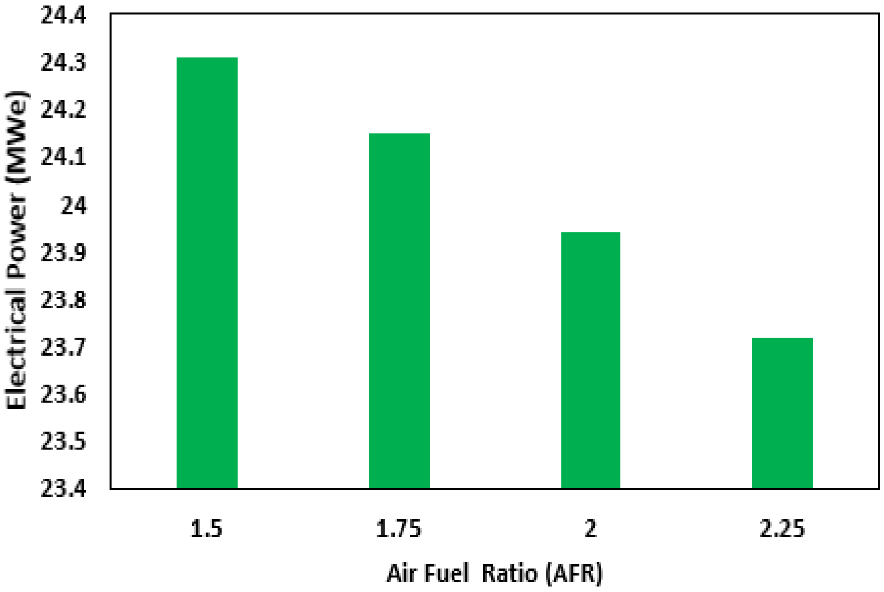

Figure 8. The air-fuel ratio vs power generator for configuration II

3.4. The correlation of the compering air and fuel in the combustor of boiler on thermal efficiency of cycle

The results presented in Figures 9 and 10 showed that the thermal efficiency tends to decrease from 32.4 to 31.6% for configuration I and 16.9 to 16.5% for configuration II due to an increase in the air-fuel ratio. This is because the fuel flow rate and energy input are constant while the net power produced by the power plant was observed to have reduced as shown in Figures 7 and 8 and this is in line with the findings of the previous study by [9]. The declining efficiency can also be related to the decreasing temperature of the inlet turbine in Figures 5 and 6 as well as the report of [27-29]. The differences of efficiency between configuration I and configuration II are caused by in configuration II include gasification efficiency but in configuration does not include gasification efficiency, so that the efficiency of configuration II is gasification efficiency multiplied with steam power plant efficiency.

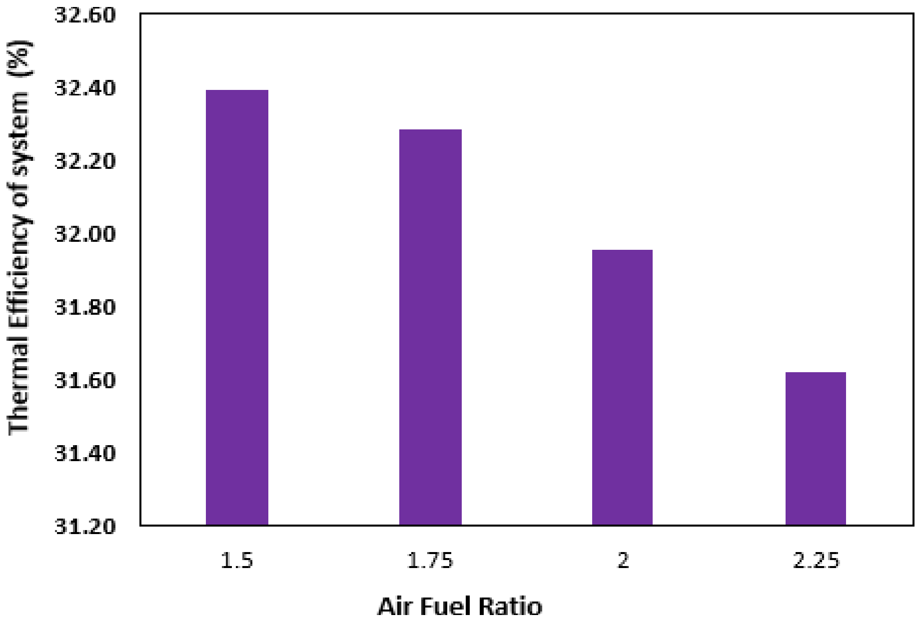

Figure 9. The air-fuel ratio vs thermal efficiency of configuration I

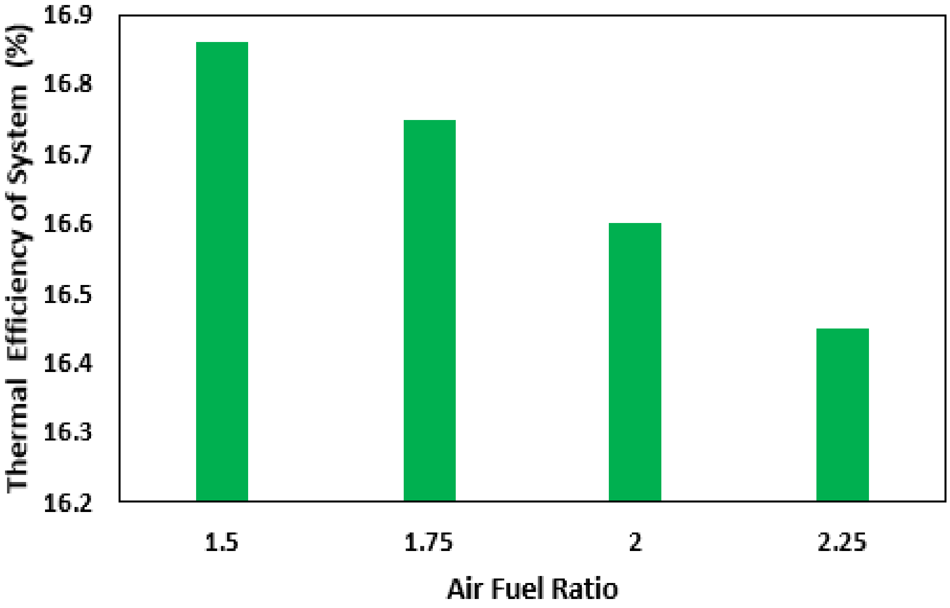

Figure 10. The air-fuel ratio vs thermal efficiency for configuration II

IV. CONCLUSION

The simulation results showed that the use of producer gas fuel which is separated from the gasification system (configuration I) and which is directly integrated with the gasification system (configuration II) gives different performances to the steam power plant system. An increase in the air-fuel ratio from 1 to 2.25 led to a reduction in the combustion temperature, steam turbine inlet temperature, power generator, and thermal system efficiency. It was discovered in the configuration I that the power and thermal efficiency decreased from 25 to 24.4 MWe and 32.4 to 31.6% respectively while configuration II had 24.3 to 23.7 MWe and 16.9 to 16.5% respectively.

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