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CYCLE-TEMPO SIMULATION OF ULTRA-MICRO GAS TURBINE FUELED BY PRODUCER GAS RESULTING FROM LEAF WASTE GASIFICATION

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Leaf waste has the potential to be converted into energy because of its high availability both in the world and Indonesia. Gasification is a conversion technology that can be used to convert leaves into producer gas. This gas can be used for various applications, one of which is using it as fuel for gas turbines, including ultra-micro gas ones, which are among the most popular micro generators of electric power at the time. To minimize the risk of failure in the experiment and cost, simulation is used. To simulate the performance of gas turbines, the thermodynamic analysis tool called Cycle-Tempo is used. In this study, Cycle-Tempo was used for the zero-dimensional thermodynamic simulation of an ultra-micro gas turbine operated using producer gas as fuel. Our research contributions are the simulation of an ultra-micro gas turbine at a lower power output of about 1 kWe and the use of producer gas from leaf waste gasification as fuel in a gas turbine. The aim of the simulation is to determine the influence of air-fuel ratio on compressor power, turbine power, generator power, thermal efficiency, turbine inlet temperature and turbine outlet temperature. The simulation was carried out on condition that the fuel flow rate of 0.005 kg/s is constant, the maximum air flow rate is 0.02705 kg/s, and the air-fuel ratio is in the range of 1.55 to 5.41. The leaf waste gasification was simulated before, by using an equilibrium constant to get the composition of producer gas. The producer gas that was used as fuel had the following molar fractions: about 22.62% of CO, 18.98% of H_2, 3.28% of CH_4, 10.67% of CO_2 and 44.4% of N_2. The simulation results show that an increase in air-fuel ratio resulted in turbine power increase from 1.23 kW to 1.94 kW. The generator power, thermal efficiency, turbine inlet temperature and turbine outlet temperature decreased respectively from 0.89 kWe to 0.77 kWe; 3.17% to 2.76%; 782 °C to 379 °C and 705°C to 304 °C. The maximums of the generator power and thermal efficiency of 0.89 kWe and 3.17%, respectively, were obtained at the 1.55 air-fuel ratio. The generator power and thermal efficiency are 0.8 kWe and 2.88%, respectively, with the 4.64 air-fuel ratio or 200% excess air. The result of the simulation matches that of the experiment described in the literature.

Keywords: *producer gas, ultra-micro gas turbine, Cycle-Tempo.*

Introduction

Converting biomass to energy could be done by using gasification technology [1–2]. Biomass gasification is still increasing commercially, which is caused by good electricity generation and efficiency, especially on small-scale power plants [3].

Leaf waste is a potential biomass source to produce energy through the gasification process [4–6]. The utilization of leaf waste in this process is generally carried out in a downdraft gasifier [7] and more specifically, an open top throatless downdraft gasifier [8–9]. The producer gas obtained from leaf waste gasification can be used for a variety of applications such as drying, combustion in internal combustion engines and gas turbines. One of the types of gas turbines is a micro gas turbine (MGT) with power below 1 MWe [10], and a MGT with power in the range of 1–10 kWe could be called an ultra-micro gas turbine (UMGT) [11]. Air-fuel ratio in the combustion chamber of a gas turbine is one of the most important parameters for the investigation of gas turbine performance. The air-producer gas ratio in a gas turbine is in the range of 3 to 5 [12–13]. Producer gas from leaf waste is still very rarely used in gas turbines.

Before conducting a direct experiment, it is necessary to initially predict the value of experimental parameters that will be used as well as the amount of power that can be generated. To do this, a thermody-

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namic simulation can be used with. Cycle-Tempo, which is currently a very popular power generation calculation software based on a thermodynamic model. The use of Cycle-Tempo in simulating gas turbine power plants has been carried out by several researchers [14–20].

There have been carried out several thermodynamic MGT simulations related to gas utilization from gasification. El-Sattar, et al. [21] simulated the use of producer gas from biomass gasification (corn stover) in MGTs whose mechanical turbine power can reach 214 kW. Altafini, et al. [22] simulated an MGT using wood waste as fuel to generate power of 50 kW. El-Sattar, et al. [23] simulated MGTs using producer gas fuels resulting from the gasification of cotton waste. The simulation was done using Cycle-Tempo. Simulation results show that the mechanical power supplied to the generator can be 71 kW. Vera, et al. [24] used Cycle-Tempo to perform a gas turbine simulation that was integrated with the biomass gasification to produce power of 30 kWe.

The literature review shows that Cycle-Tempo simulations have only been carried out on MGTs, As far as UMGTs are concerned, no simulations have been reported from the researchers. In addition, the researchers have not reported the use of producer gas from leaf waste gasification as fuel for UMGTs.

In this study was simulated a UMGT using producer gas from leaf waste as fuel to produce power of about 1 kWe. The simulation was done using Cycle-Tempo with the variation of air-fuel ratio in the combustion chamber. The novelty of the research is the use of producer gas from leaf waste gasification as fuel for gas turbines and simulation of a UMGT with Cycle-Tempo.

Methodology

The simulation was carried out using the producer gas composition from the thermodynamic simulation using an equilibrium constant of leaf waste gasification [25]. The composition of the producer gas used in the simulation is shown in table 1 [25]. The simulation was carried out on condition that the fuel mass flow rate is constant, the air flow rate is variable, and the air-fuel ratio is variable as shown in table 2. The combustion process in the combustion chamber takes place at a pressure of 1.513 bar. The efficiencies of gas turbine components were taken to be equal to Cycle-Tempo default values.

Fig. 1 shows the block diagram of UMGT simulation using Cycle-Tempo.

Table 1. Producer Gas Composition [25]

Constituent	Molar fraction
CO	22.62%
H_2	18.98%
CH_4	3.29%
CO_2	10.67%
N_2	44.44%

Table 2. Fuel mass flow rate, air mass flow rate, and air-fuel ratio values

Fuel mass flow rate, kg/s	Air mass flow rate, kg/s	Air-fuel ratio
0.005	0.00927	1.854
0.005	0.01159	2.318
0.005	0.01546	3.092
0.005	0.02319	4.638
0.005	0.02705	5.411

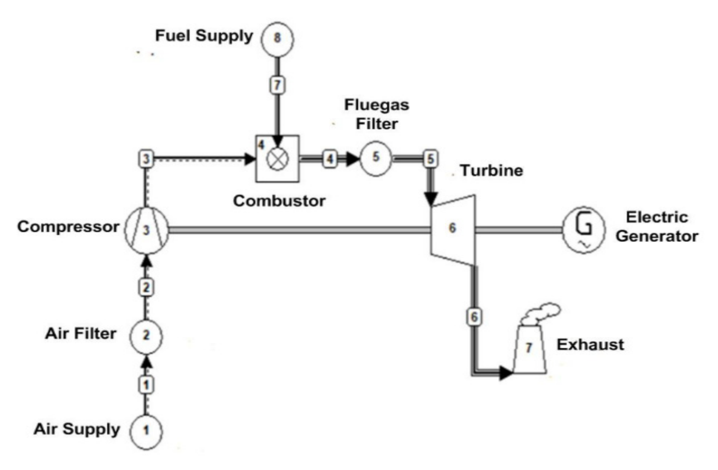

Fig. 1. Block diagram of UMGT simulation using Cycle-Tempo

Results and Discussions

Fig. 2 shows the influence of air-fuel ratio on the mechanical power of the compressor. The increase in air-fuel ratio resulted in the increase in the mechanical power of the compressor from 0.33 kW to 1.15 kW for the increase in air fuel-ratio from 1.55 to 5.41, with an average increase by 28.93%. The increase in air-fuel ratio caused the increase in the mass flow rate of the air flowing through the compressor. It required an increase in the mechanical power of the compressor.

Fig. 3 shows the influence of air-fuel ratio on the mechanical power produced by the turbine. The increase in air fuel-ratio resulted in the increase in the mechanical power of the turbine from 1.23 kW to 1.94 kW for the increase in air-fuel ratio from 1.55 to 5.41, with an average increase by 9.6%. The increase in air-fuel ratio caused the increase in the mass flow rate of the flue gas flowing through the turbine. The increase in the mass flow rate of the flue gas caused the turbine blades to rotate faster, increasing the mechanical power of the turbine. The resulting turbine power produced matches the results of the experiment conducted by F. Vidian et al [26].

Fig. 4 shows the influence of air-fuel ratio on the power produced by the generator. The increase in air-fuel ratio resulted in the decrease in the generator power from 0.89 kWe to 0.77 kWe for the increase in air-fuel ratio from 1.55 to 5.41, with an average decrease by 2.8%. The increase in air-fuel ratio caused the increase in the power needed by the compressor, which, on average, is more significant (28.93%), compared with the average increase in the mechanical power generated by the turbine (9.6%). Generator power is the net power generated, i.e. the mechanical power of the turbine minus the mechanical power of the compressor. In the field, a gas turbine system usually works under the condition of 200% excess air or at an air-fuel ratio of 4.64, In this simulation, under these conditions, the power that can be generated reaches 0.8 kWe.

Fig. 5 shows the influence of air-fuel ratio on thermal efficiency. The increase in air-fuel ratio resulted in the decrease in the thermal efficiency of the system from 3.17% to 2.76% for the increase in air-fuel ratio from 1.55 to 5.41, with an average decrease by 2.7%. The thermal efficiency was greatly influenced by the decrease in the power of the generator, where thermal efficiency is the power of the generator divided by the input energy, the value of the latter being constant. This result matches the result reported by M. M. Rahaman et al [27] and Ankit Kumar et al [28].

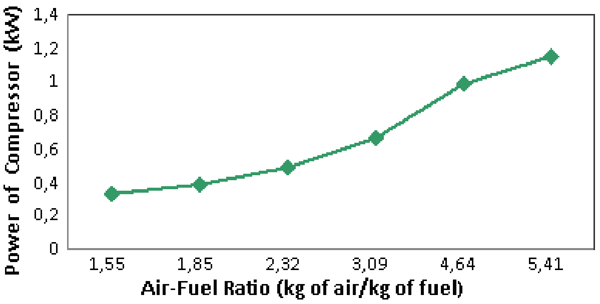

Fig. 2. Influence of AFR on the power of the compressor

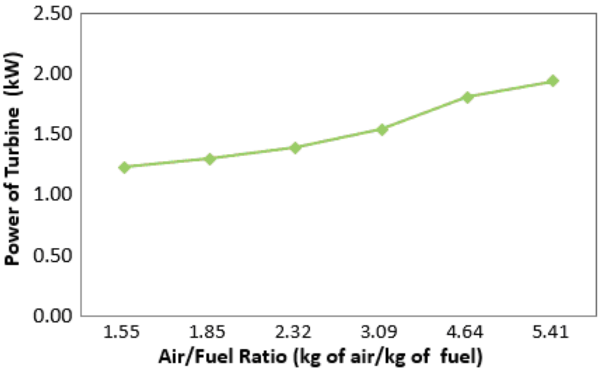

Fig. 3. Influence of AFR on the power of the turbine

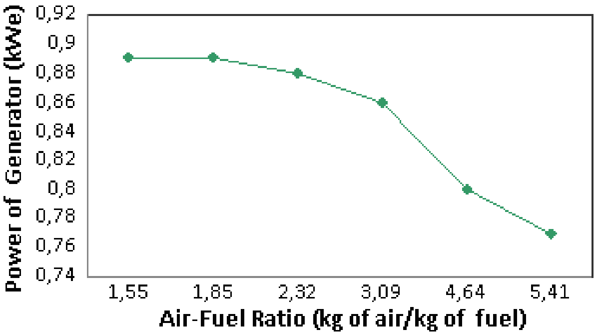

Fig. 4. Influence of ARF on the power of the generator

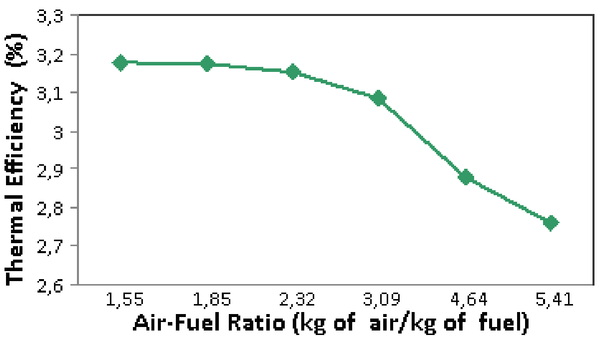

Fig. 5. Influence of AFR on thermal efficiency

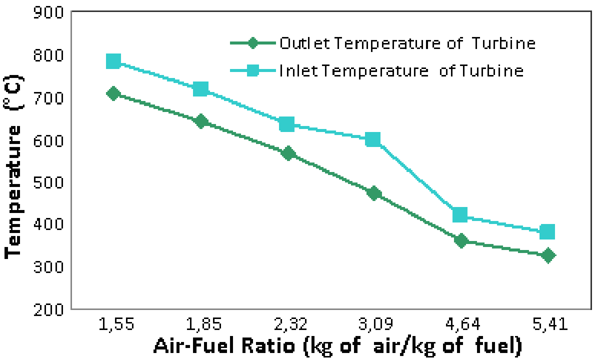

Fig. 6. Influence of ARF on the inlet and outlet temperatures of the turbine

Fig. 6 shows the influence of air-fuel ratio on the turbine inlet and outlet temperatures. The increase in air-fuel ratio resulted in the decrease in the turbine inlet and outlet temperatures. The inlet temperature decreased from 782 °C to 379 °C for the increase in air-fuel ratio from 1.55 to 5.41, with an average decrease by 13%. The outlet temperature decreased from 705 °C to 304 °C for the increase in air-fuel ratio from 1.55 to 5.41, with an average decrease by 14.2%. This is due to the increase in the mass flow rate of Nitrogen as an effect of the increased air-fuel ratio. Nitrogen absorbed the heat released in the combustion process, causing a drop in the flue gas temperature. The gas expanded when it passed through the turbine, which is why the turbine outlet temperature decreased. These results match the simulation results reported by F. R. Martínez et. al. [29] and the result of the experiment by F. Vidian et al. [26].

The leaf waste can be used directly to feed the gasifier in the gasification process, which will reduce the cost of fuel preparation. The power plant could be constructed portable so that it could be installed near the fuel source, which would reduce transportation costs. An UMGT could be a development of a low-cost turbo charger. UMGTs use producer gas from leaf waste gasification as fuel because the gas has competitive cost compared to the fuel in other micro power systems. This system is also a method for solving environmental problems related to the disposal or reduction of the volume of leaf waste.

Conclusions

The results of simulation show that the producer gas from leaf waste gasification as an alternative fuel for UMGTs has been used successfully. The leaf waste is a very promising alternative fuel for gas turbines. The maximum of the generator power and thermal efficiency were 0.89 kWe and 3.17%, respectively, at an air-fuel ratio of 1.55. Under the condition of 200% excess air or air-fuel ratio of 4.64, the generator power and thermal efficiency were 0.8 kWe and 2.88%, respectively. The low of cost of fuel preparation, fuel transportation and equipment make UMGTs using producer gas from leaf waste gasification more competitive with other micro power plants. This system could solve the environmental problems of disposing of or reducing the volume of leaf waste.

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Моделювання мікротурбіни, що працює на отриманому в результаті газифікації опалого листя генераторному газі, за допомогою Cycle-Tempo

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Опале листя має великий потенціал для перетворення в енергію завдяки його великій доступності в світі, і в Індонезії у тому числі. Газифікація – це технологія для перетворення листя в генераторний газ. Цей газ можна застосовувати для різних цілей, зокрема як паливо для газових турбін, включаючи мікротурбіни, що є на цей час одними з найпопулярніших мікрогенераторів електроенергії. Щоб звести до мінімуму ризик невдачі під час проведення експериментів і пов'язані з ними витрати, використовується моделювання. Для моделювання роботи газової турбіни застосовується інструмент термодинамічного аналізу Cycle-Tempo. У цьому дослідженні за допомогою Cycle-Tempo виконано нульмерне моделювання мікротурбіни, що використовує як паливо генераторний газ. Нашим внеском в дослідження є моделювання газової мікротурбіни з меншою вихідною електричною потужністю, близько 1 кВт, і вивчення можливості використання генераторного газу, отриманого в результаті газифікації опалого листя, як палива для газової турбіни. Мета моделювання – визначити ступінь впливу співвідношення повітря-паливо на потужність компресора, турбіни, електрогенератора, термічний коефіцієнт корисної дії (ККД), температуру на вході в турбіну і на виході з неї. Моделювання проводилося при постійній витраті палива 0,005 кг/с, максимальній витраті повітря 0,02705 кг/с і співвідношенні повітря-паливо в діапазоні від 1,55 до 5,41. Газифікація листя була змодельована раніше з використанням константи рівноваги для отримання складу генераторного газу. Як паливо використовувався генераторний газ, атомні частки якого становили близько 22,62% CO; 18,98% H_2; 3,28% CH_4; 10,67% CO_2 і 44,4% N_2. Результати моделювання показали, що збільшення співвідношення повітря-паливо приводить до збільшення потужності турбіни з 1,23 до 1,94 кВт. Потужність електрогенератора, термічний ККД, температура на вході турбіни і на виході з неї знизилися, відповідно, з 0,89 до 0,77 кВт; з 3,17 до 2,76%; з 782 до 379 ° C і з 705 до 304 ° C. Максимальні потужність електрогенератора і термічний ККД, відповідно, 0,89 кВт і 3,17%, були отримані при співвідношенні повітря-паливо 1,55. Потужність електрогенератора і термічний ККД склали 0,8 кВт і 2,88%, відповідно, при співвідношенні повітря-паливо 4,64 або при надлишку повітря 200%. Результат моделювання аналогічний результату, отриманому в ході експерименту, описаному в літературі.

Ключові слова: *генераторний газ, газова мікротурбіни, Cycle-Tempo.*

Література

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