CYCLE-TEMPO SIMULATION OF ULTRA-MICRO GAS

by Fajri Vidian

DOI: https://doi.org/10.15407/pmach2021.03.014

UDC 621.4

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

[1] **Fajri Vidian**
fajri.vidian@unsri.ac.id
ORCID: 0000-0002-7136-7331

[1] **Putra Anugrah Peranginangin**
ptranugrah2106@gmail.com
ORCID: 0000-0003-2782-0108

[2] **Muhamad Yulianto**
Muhamad_yulianto@yahoo.com
ORCID: 0000-0003-1761-348X

[1] Department of Mechanical Engineering, Faculty of Engineering, Sriwijaya University,
Jalan Raya Palembang-Prabumulih km 32, Indralaya, Ogan Ilir, South Sumatra, 30662, Indonesia

[2] Research Institute for Science and Engineering, Department of Applied Mechanics, Waseda University,
3-4-1, Okubo, Shinjuku, Tokyo, 169-8555, Japan

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 thermodynamic 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

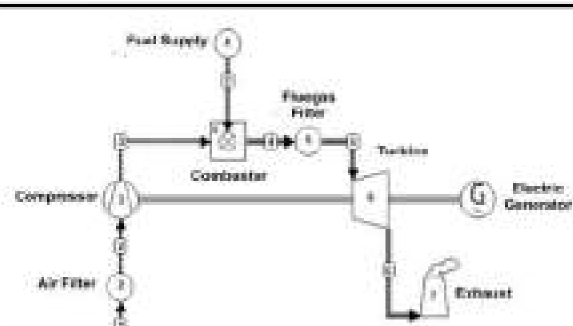

Fig. 1. Block diagram of UMGT simulation using Cycle-Tempo

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].

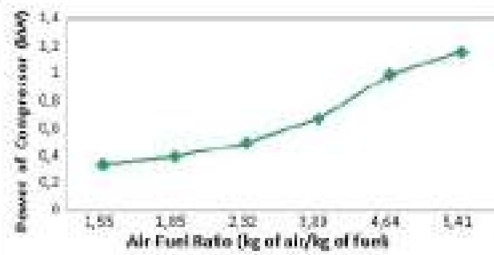

Fig. 2. Influence of AFR on the power of the compressor

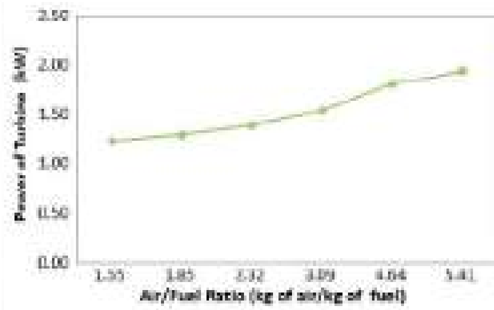

Fig. 3. Influence of AFR on the power of the turbine

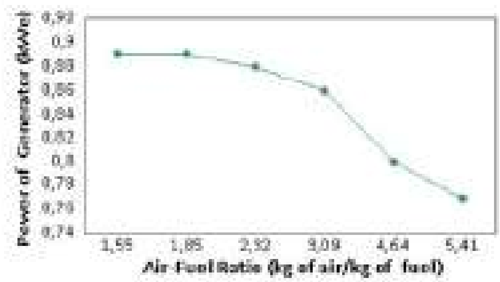

Fig. 4. Influence of ARF on the power of the generator

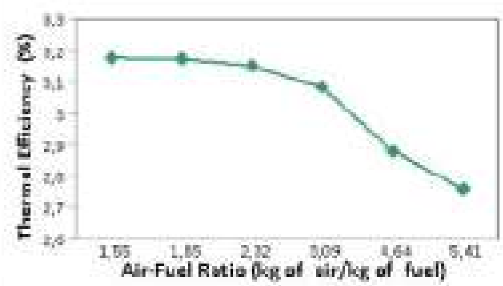

Fig. 5. Influence of AFR on thermal efficiency

Fig. 6 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. Martinez et. al. [29] and the result of the experiment by F. Vidian et al. [26].

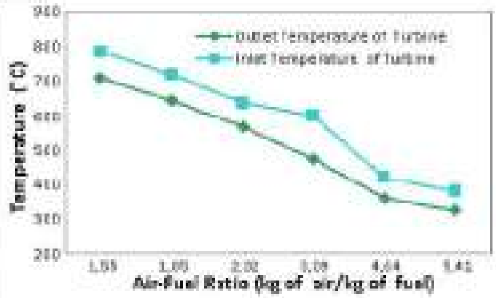

Fig. 6. Influence of ARF on the inlet and outlet temperatures of the turbine

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.

Acknowledgment

This research was done using Cycle-Tempo, supported by the Department of Mechanical Engineering, University Indonesia.

References

1. Tursi, A. (2019). A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Research Journal*, vol. 6, iss. 2, pp. 962–979. https://doi.org/10.18331/BRJ2019.6.2.3
2. Lestari, N. A. (2019). Reduction of CO_2 emission by integrated biomass gasification-solid oxide fuel cell combined with heat recovery and in-situ CO_2 utilization. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, vol. 6, iss. 3, pp. 254–261. https://doi.org/10.5109/2349302.
3. Furutani, Y., Norinaga, K., Kudo, S., Hayashi, J., & Watanabe, T. (2017). Current situation and future scope of biomass gasification in Japan. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, vol. 4, iss. 4, pp. 24–29. https://doi.org/10.5109/1929681.
4. Shah, S. A. & Ghodke, S. A. (2017). Physico-chemical evaluation of leaf litter biomass as feedstock for gasification. *International Journal of Engineering Research and Technology*, vol. 10, no. 1, pp. 227–231.
5. Rao, G. A., Vidhisha, M., & Chowdary, M. S. (2017). Development of bio mass gasification for thermal applications. *International Journal of Civil Engineering and Technology (IJCIET)*, vol. 8, iss. 6, pp. 109–124.
6. Shone, C. M. & Jothi, T. J. S. (2016). Preparation of gasification feedstock from leafy biomass. *Environmental Science and Pollution Research*, vol. 23, pp. 9364–9372. https://doi.org/10.1007/s11356-015-5367-2.
7. Kumar, A. & Randa, R. (2014). Experimental analysis of a producer gas generated by a Chir pine needle (leaf) in a downdraft biomass gasifier. *International Journal of Engineering Research and Applications*, vol. 4, iss. 10, pp. 122–130.

8. Jorapur, R. M. & Rajvanshi, A. K. (1995). Development of a sugarcane leaf gasifier for electricity generation. *Biomass and Bioenergy*, vol. 8, iss. 2, pp. 91–98. https://doi.org/10.1016/0961-9534(94)00049-Y.
9. Jorapur, R. & Rajvanshi, A. K. (1997). Sugarcane leaf-bagasse gasifiers for industrial heating applications. *Biomass and Bioenergy*, vol. 13, iss. 3, pp. 141–146. https://doi.org/10.1016/S0961-9534(97)00014-7.
10. Al-attab, K. A. & Zainal, Z. A. (2015). Externally fire gas turbine technology: A review. *Applied Energy*, vol. 138, pp. 474–487. https://doi.org/10.1016/j.apenergy.2014.10.049.
11. Calabria, A., Capata, R., Di Veroli, M., & Pepe, G. (2013). Testing of the ultra-micro gas turbine devices (1–10 kW) for portable power generation at university of Roma 1: First tests results. *Engineering*, vol. 5, no. 5, pp. 481–489. https://doi.org/10.4236/eng.2013.55058.
12. Al-Attab, K. A. & Zainal, Z. A. (2014). Performance of a biomass fueled two-stage micro gas turbine (MGT) system with hot air production heat recovery unit. *Applied Thermal Engineering*, vol. 70, iss. 1, pp. 61–70. https://doi.org/10.1016/j.applthermaleng.2014.04.030.
13. Sridhar, H. V., Sridhar, G., Dassapa, S., Paul, P. J., & Mukunda, H. S. (2007). On the operation of high pressure biomass gasifier with gas turbine. *15th European Biomass Conference and Exhibition*, 7–11 May 2007, Berlin, Germany, pp. 964–967.
14. Kadhim, H. T., Jabbar, F. A., Rona, A., & Bagdanaviciu, A. (2018). Improving the performance of gas turbine power plant by modified axial turbine. *International Journal of Mechanical and Mechatronics Engineering*, vol. 12, no. 6, pp. 690–696.
15. Kishore, S., Reddi, L. M., Daniel, J., & Sreekanth, M. (2018). Thermodynamic study of a 250 MWe combined cycle power plant at full load and part load conditions. *International Journal of Mechanical Engineering and Technology (IJMET)*, vol. 9, iss. 4, pp. 870–877.
16. Aravind, P. V., Schilt, C., Türker, B., & Woudstra, T. (2012). Thermodynamic model of a very high efficiency power plant based on a biomass gasifier, SOFCs, and a gas turbine. *International Journal of Renewable Energy Development*, vol. 1, no. 2, pp. 51–55. https://doi.org/10.14710/ijred.1.2.51-55.
17. Azami, V. & Yari, M. (2017). Comparison between conventional design and cathode gas recirculation design of a direct-syngas solid oxide fuel cell– gas turbine hybrid systems Part I: Design performance. *International Journal of Renewable Energy Development*, vol. 6, no. 2, pp. 127–136. https://doi.org/10.14710/ijred.6.2.127-136.
18. Ozgoli, H. A. (2017). Simulation of integrated biomass gasification – gas turbine – air bottoming cycle as an energy efficient system. *International Journal of Renewable Energy Research – IJRER*, vol. 7, no. 1 (2017), pp. 275–284.
19. Utomo, B., Widodo, K., & Fathoni, R. (2016). Thermodynamic study on a combined cycle power plant of 500 MW under various loads using cycle-tempo. *AIP Conferences Proceedings*, 1778, pp. 030021-1–030021-6.
20. Amirantea, R., De Palmaa, P., Distasoa, E., La Scalab, M., & Tamburranoa, P. (2017). Experimental prototype development and performance analysis of a small-scale combined cycle for energy generation from biomass. *Energy Procedia*, vol. 126, pp. 659–666. https://doi.org/10.1016/j.egypro.2017.08.294.
21. El-Sattar, H. A., Kamel, S., Tawfik, M. A., Vera, D., & Jurado, F. (2019). Modeling and simulation of corn stover gasifier and micro-turbine for power generation. *Waste and Biomass Valorization*, vol. 10, pp. 3101–3114. https://doi.org/10.1007/s12649-018-0284-z.
22. Altafini, C. R. & Wander, P. R. (2005). Modeling of wood waste fuel cell/gas turbine for small power generation. 18th *International Congress of Mechanical Engineering*, Ouro Preto, MG.
23. El-Sattar, H. A., Kamel, S., Tawfik, M. A., & Vera, D. (2016). Modeling of a downdraft gasifier combined with externally fired gas turbine using rice straw for generating electricity in Egypt. *Eighteenth International Middle East Power Systems Conference (MEPCON)*, Cairo, Egypt. https://doi.org/10.1109/MEPCON.2016.7836977.
24. Vera, D., Jurado, F., de Mena, B., & Schories, G. (2011). Comparison between externally fired gas turbine and gasifier-gas turbine system for the olive oil industry. *Energy*, vol. 36, iss. 12, pp. 6720–6730. https://doi.org/10.1016/j.energy.2011.10.036.
25. Vidian, F. & Sahputra, Y. A. (2016). Simulasi secara termodinamika gasifikasi limbah daun pada downdraft gasifier menggunakan model konstanta kesetimbangan: Pengaruh equivalent ratio. *Proceeding Seminar Nasional Tahunan Teknik Mesin XV (SNTTM XV)*, 5–6 October 2016, Bandung, pp. 258–264.
26. Vidian, F., Basri, H., Alian, H., Zhafran, E., & Aziad, T. (2018). Preliminary study on single stage micro gas turbine integrated with South Sumatera Indonesia low rank coal gasification. *Ecology, Environment and Conservation*, vol. 24, iss. 4, pp. 1529–1533.
27. Rahman, M. M., Ibrahim, T. K., & Abdalla, A. N. (2011). Thermodynamic performance analysis of gas-turbine power plant. *International Journal of the Physical Sciences*, vol. 6, no. 14, pp. 3539–3550.
28. Kumar, A., Singhania, A., Sharma, A. K., Roy, R., & Mandal, B. K. (2017). Thermodynamic analysis of gas turbine power plant. *International Journal of Innovative Research in Engineering & Management (IJIREM)*, vol. 4, iss. 3, pp. 648–654. https://doi.org/10.21276/ijirem.2017.4.3.2.
29. Martinez, F. R., Martínez, A. R., Velázquez, M. T., Diez, P. Q., Eslava, G. T., & Francis, J. A. (2011). Evaluation of the gas turbine inlet temperature with relation to the excess air. *Energy and Power Engineering*, vol. 3, no. 4, pp. 517–524. https://doi.org/10.4236/epe.2011.34063.

Received 25 May 2021

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

[1] Fajri Vidian, [1] Putra Anugrah Peranginangin, [2] Muhamad Yulianto

[1] Кафедра машинобудування, інженерний факультет, Університет Шрівіджая,
Шосе Палембанг-Прабумуліх км 32, Індралая, Оган Ілір, Південна Суматра, 30662, Індонезія

[2] Науково-дослідний інститут науки і техніки, Департамент прикладної механіки, Університет Васеда,
3-4-1, Окубо, Сінзюку, Токіо, 169-8555, Японія

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 ним витрати, використовується моделювання. Для моделювання роботи газової турбіни застосовується інструмент термодинамічного аналізу Cycle-Tempo. У цьому дослідженні за допомогою Cycle-Tempo виконано чисельне моделювання мікротурбіни, що використовує як паливо генераторний газ. Новим 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 22,02% CO; 18,98% H_2; 5,28% 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 мікротурбіна, Cycle-Tempo.*

Література

1. Tursi A. A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Research Journal*. 2019. Vol. 6. Iss. 2. P. 962–979. https://doi.org/10.18331/BRJ2019.6.2.3.
2. Lestari N. A. Reduction of CO_2 emission by integrated biomass gasification-solid oxide fuel cell combined with heat recovery and in-situ CO_2 utilization. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*. 2019. Vol. 6. Iss. 3. P. 254–261. https://doi.org/10.5109/2349302.
3. Furutani Y., Norinaga K., Kudo S., Hayashi J., Watanabe T. Current situation and future scope of biomass gasification in Japan. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*. 2017. Vol. 4. Iss. 4. P. 24–29. https://doi.org/10.5109/1929681.
4. Shah S. A., Ghodke S. A. Physico-chemical evaluation of leaf litter biomass as feedstock for gasification. *International Journal of Engineering Research and Technology*. 2017. Vol. 10. No. 1. P. 227–231.
5. Rao G. A., Vidhisha M., Chowdary M. S. Development of bio mass gasification for thermal applications. *International Journal of Civil Engineering and Technology (IJCIET)*. 2017. Vol. 8. Iss. 6. P. 109–124.
6. Shone C. M., Jothi T. J. S. Preparation of gasification feedstock from leafy biomass. *Environmental Science and Pollution Research*. 2016. Vol. 23. P. 9364–9372. https://doi.org/10.1007/s11356-015-5167-2.
7. Kumar A., Randa R. Experimental analysis of a producer gas generated by a Chir pine needle (leaf) in a downdraft biomass gasifier. *International Journal of Engineering Research and Applications*. 2014. Vol. 4. Iss. 10. P. 122–130.
8. Jorapur R. M., Rajvanshi A. K. Development of a sugarcane leaf gasifier for electricity generation. *Biomass and Bioenergy*. 1995. Vol. 8. Iss. 2. P. 91–98. https://doi.org/10.1016/0961-9534(94)00049-Y.
9. Jorapur R., Rajvanshi A. K. Sugarcane leaf-bagasse gasifiers for industrial heating applications. *Biomass and Bioenergy*. 1997. Vol. 13. Iss. 3. P. 141–146. https://doi.org/10.1016/S0961-9534(97)00014-7.

10. Al-attab K. A., Zainal Z. A. Externally fire gas turbine technology: A review. *Applied Energy*. 2015. Vol. 138. P. 474–487. https://doi.org/10.1016/j.apenergy.2014.10.049.
11. Calabria A., Capata R., Di Veroli M., Pepe G. Testing of the ultra-micro gas turbine devices (1–10 kW) for portable power generation at university of Roma 1: First tests results. *Engineering*. 2013. Vol. 5. No. 5. P. 481–489. https://doi.org/10.4236/eng.2013.55058.
12. Al-Attab K. A., Zainal Z. A. Performance of a biomass fueled two-stage micro gas turbine (MGT) system with hot air production heat recovery unit. *Applied Thermal Engineering*. 2014. Vol. 70. Iss. 1. P. 61–70. https://doi.org/10.1016/j.applthermaleng.2014.04.030.
13. Sridhar H. V., Sridhar G., Dasappa S., Paul P. J., Mukunda H. S. On the operation of high pressure biomass gasifier with gas turbine. *15th European Biomass Conference and Exhibition*, 7–11 May 2007, Berlin, Germany, 2007. P. 964–967.
14. Kadhim H. T., Jabbar F. A., Rona A., Bagdanavicius A. Improving the performance of gas turbine power plant by modified axial turbine. *International Journal of Mechanical and Mechatronics Engineering*. 2018. Vol. 12. No. 6. P. 690–696.
15. Kishore S., Reddi L. M., Daniel J., Sreekanth M. Thermodynamic study of a 250 MWe combined cycle power plant at full load and part load conditions. *International Journal of Mechanical Engineering and Technology (IJMET)*. 2018. Vol. 9. Iss. 4. P. 870–877.
16. Aravind P. V., Schilt C., Türker B., Woudstra T. Thermodynamic model of a very high efficiency power plant based on a biomass gasifier, SOFCs, and a gas turbine. *International Journal of Renewable Energy Development*. 2012. Vol. 1. No. 2. P. 51–55. https://doi.org/10.14710/ijred.1.2.51-55.
17. Azami V., Yari M. Comparison between conventional design and cathode gas recirculation design of a direct-syngas solid oxide fuel cell– gas turbine hybrid systems Part I: Design performance. *International Journal of Renewable Energy Development*. 2017. Vol. 6. No. 2. P. 127–136. https://doi.org/10.14710/ijred.6.2.127-136.
18. Ozgoli H. A. Simulation of integrated biomass gasification – gas turbine – air bottoming cycle as an energy efficient system. *International Journal of Renewable Energy Research – IJRER*. 2017. Vol. 7. No. 1 (2017). P. 275–284.
19. Utomo B., Widodo K., Fathoni R. Thermodynamic study on a combined cycle power plant of 500 MW under various loads using cycle-tempo. *AIP Conf. Proc.* 2016. 1778. P. 030021-1–030021-6.
20. Amirante R., De Palma P., Distaso E., La Scala M., Tamburrano P. Experimental prototype development and performance analysis of a small-scale combined cycle for energy generation from biomass. *Energy Procedia*. 2017. Vol. 126. P. 659–666. https://doi.org/10.1016/j.egypro.2017.08.294.
21. El-Sattar H. A., Kamel S., Tawfik M. A., Vera D., Jurado F. Modeling and simulation of corn stover gasifier and micro-turbine for power generation. *Waste and Biomass Valorization*. 2019. Vol. 10. P. 3101–3114. https://doi.org/10.1007/s12649-018-0284-z.
22. Altafini C. R., Wander P. R. Modeling of wood waste fuel cell/gas turbine for small power generation. 18th *International Congress of Mechanical Engineering*. Ouro Preto, MG. 2005.
23. El-Sattar H. A., Kamel S., Tawfik M. A., Vera D. Modeling of a downdraft gasifier combined with externally fired gas turbine using rice straw for generating electricity in Egypt. *Eighteenth International Middle East Power Systems Conference (MEPCON)*. Cairo, Egypt. 2016. https://doi.org/10.1109/MEPCON.2016.7836977.
24. Vera D., Jurado F., de Mena B., Schories G. Comparison between externally fired gas turbine and gasifier-gas turbine system for the olive oil industry. *Energy*. 2011. Vol. 36. Iss. 12. P. 6720–6730. https://doi.org/10.1016/j.energy.2011.10.036.
25. Vidian F., Sahputra Y. A. Simulasi secara termodinamika gasifikasi limbah daun pada downdraft gasifier menggunakan model konstanta kesetimbangan: Pengaruh equivalent ratio. *Proceeding Seminar Nasional Tahunan Teknik Mesin XV (SNTTM XV)*, 5–6 October 2016, Bandung, 2016. P. 258–264.
26. Vidian F., Basri H., Alian H., Zhafran E., Aziad T. Preliminary study on single stage micro gas turbine integrated with South Sumatera Indonesia low rank coal gasification. *Ecology, Environment and Conservation*. 2018. Vol. 24. Iss. 4. P. 1529–1533.
27. Rahman M. M., Ibrahim T. K., Abdalla A. N. Thermodynamic performance analysis of gas-turbine power plant. *International Journal of the Physical Sciences*. 2011. Vol. 6. No. 14. P. 3539–3550.
28. Kumar A., Singhania A., Sharma A. K., Roy R., Mondal B. K. Thermodynamic analysis of gas turbine power plant. *International Journal of Innovative Research in Engineering & Management (IJIREM)*. 2017. Vol. 4. Iss. 3. P. 648–654. https://doi.org/10.21276/ijirem.2017.4.3.2.
29. Martínez F. R., Martínez A. R., Velázquez M. T., Diez P. Q., Eslava G. T., Francis J. A. Evaluation of the gas turbine inlet temperature with relation to the excess air. *Energy and Power Engineering*. 2011. Vol. 3. No. 4. P. 517–524. https://doi.org/10.4236/epe.2011.34063.

CYCLE-TEMPO SIMULATION OF ULTRA-MICRO GAS

ORIGINALITY REPORT

14%	6%	14%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

4%

★ Yujin Cong, Huibing Gan, Huaiyu Wang. "Parameter investigation of the pilot fuel post-injection strategy on performance and emissions characteristics of a large marine two-stroke natural gas-diesel dual-fuel engine", Fuel, 2022

Publication

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		