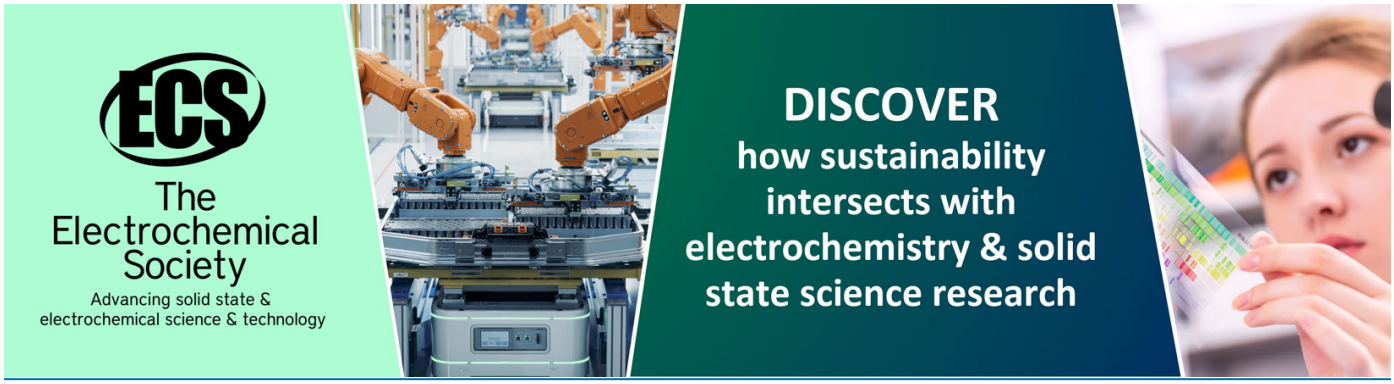
Performance Analysis of SOFC / GT Combined Cycle System with Preheater in Front of Turbine



Performance Analysis of SOFC / GT Combined Cycle System with Preheater in Front of Turbine

Lao Xingsheng*, Liao Mengran, MaCan and Dai Chunhui

Science and Technology on Thermal Energy and Power Laboratory, Wuhan 2nd Ship Design and Research Institute, Wuhan, 430205, P.R. China

*laoxingsheng@tsinghua.org.cn

*Corresponding author's e-mail: 460079620@qq.com

Abstract. Based on the SOFC zero-dimensional model, a SOFC turbine combined cycle simulation platform is established. For the SOFC/GT combined cycle system configuration scheme with the preheater placed in front of the turbine, the influence of cycle parameters on system performance is analyzed. The current density-power characteristic curves at different outlet pressures, the fuel flow-efficiency characteristic curve and the turbine inlet temperature curve at different fuel utilization rates were calculated and analyzed separately when different low-temperature and intermediate-temperature combined cycle system configurations were used. The results show that the low-temperature SOFC/GT cycle maintains high-efficiency design conditions with a fuel utilization rate of 0.8-0.85, and the highest efficiency is about 52%. The design working pressure of the medium temperature SOFC/GT cycle is suggested to be 0.4MPa-0.5MPa, and the system efficiency will be higher than 50% when the compression ratio is at 0.8-0.85, and the maximum efficiency is about 64%.

1. Introduction

Solid oxide fuel cells (SOFCs) have the advantages of a wide range of applicable fuel temperatures, high energy utilization rates, environmental friendliness, no pollution, and high stability, and are receiving increasing attention in the field of marine equipment[1]. How to improve the total energy utilization rate through the combined cycle of SOFC and gas turbine (GT) is the forefront and hot spot of current research[2-3]. Based on the SOFC zero-dimensional model, a SOFC turbine combined cycle simulation platform is established in this paper. For the SOFC / GT combined cycle system configuration scheme in which the preheater is arranged in front of the turbine, the influence of cycle parameters on system performance is analyzed.

2. Combined cycle system configuration

Directly driving the turbine to perform work with SOFC exhaust gas will cause the turbine's intake air temperature to be higher and place higher demands on the turbine[4]. If the preheater is arranged in front of the turbine, the high temperature and high pressure exhausted from the combustion chamber are used to directly preheat the intake air and then enter the turbine, reducing the intake air temperature of the turbine, which will have a certain degree of impact on the turbine power and system efficiency[5]. Schematic composition diagram is shown in figure 1.

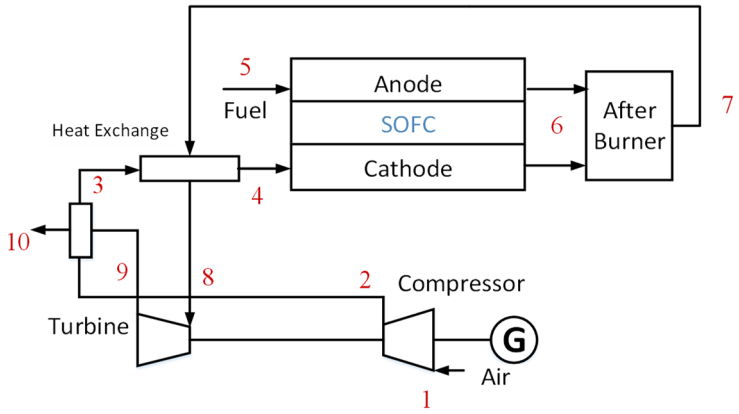


Figure 1. Schematic diagram of the presenting configuration

3. Calculation results and analysis

3.1. Performance of Medium Temperature SOFC Combined Cycle System

The intermediate temperature SOFC / GT cycle output power is shown in figure 2. The fuel efficiency of the SOFC is assumed to be 0.85, and the output power of the SOFC / GT cycle is the lowest when the compressor outlet pressure is 0.5 MPa.

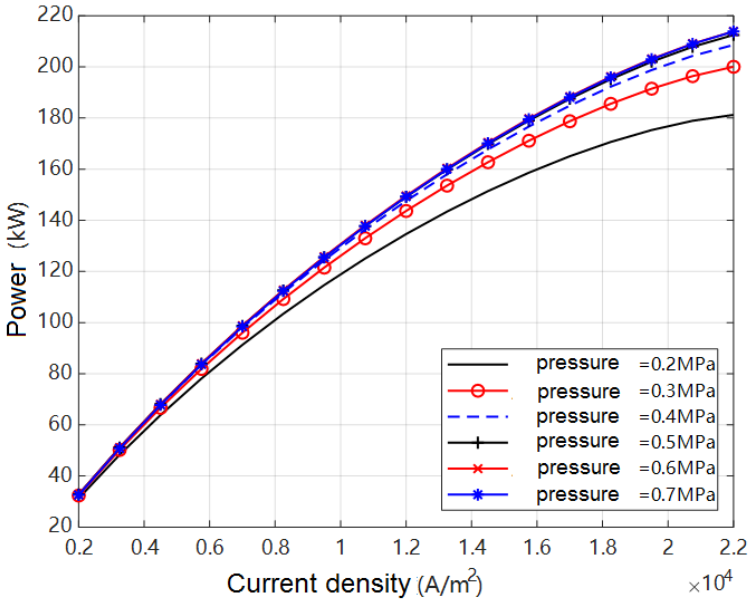
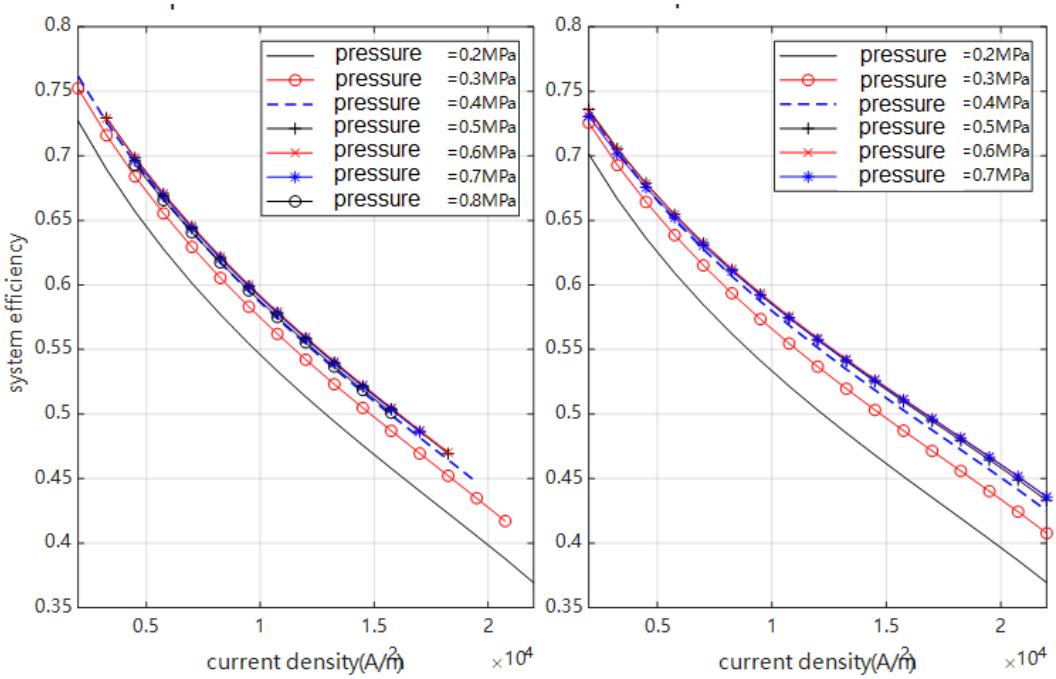


Figure 2. Current density-power characteristic curve under different working pressure

The efficiency curve comparison of the preheater before and after the turbine is shown in figure 3. With the same output current density, the system efficiency of the preheater before the turbine is about 3% lower on average, that is, the preheater is located after the turbine. At this time, the gas turbine has higher power and higher energy efficiency. When the preheater is arranged behind the turbine, the turbine inlet temperature is around 960 ℃. When the preheater is arranged in front of the turbine, the turbine inlet temperature is in the range of 730℃-780 ℃, which is reduced by nearly 200 ℃.



(a) Preheater after turbine (b) Preheater in front of turbine

Figure 3. Current density-efficiency characteristic curves under different working pressures

Select 0.3MPa as the outlet pressure of the compressor. The performance change of SOFC/GT cycle system caused by different SOFC fuel utilization and current density was studied. The power curve of the medium-temperature SOFC/GT cycle system is shown in figure 4, and each curve drops by 30kW-50kW as a whole. As the fuel flow increases, the magnitude of the decrease decreases. The efficiency curves are shown in figure 5, with each curve decreasing by 1%–3% overall.

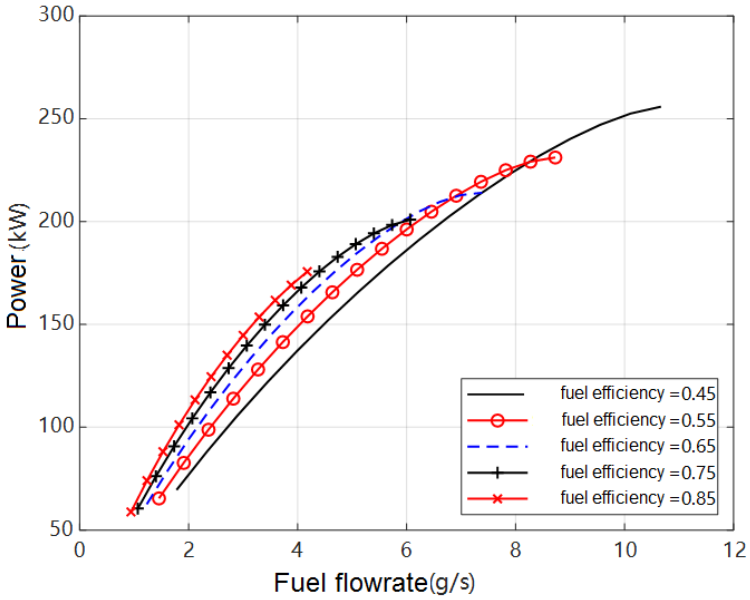


Figure 4. Fuel flow-power characteristic curve of medium temperature fuel cell system

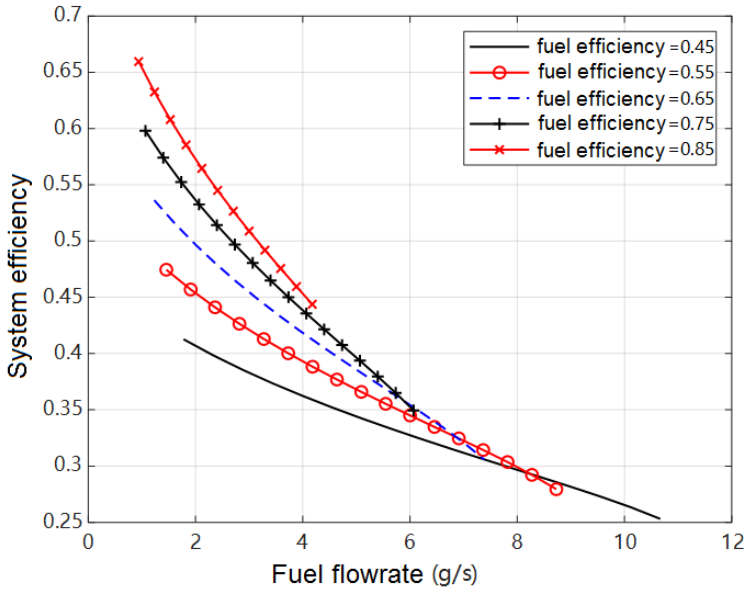


Figure 5. Fuel flow-efficiency characteristic curve of medium temperature fuel cell system

3.2. Performance of low temperature SOFC combined cycle system

For low-temperature SOFC, the output current density range is to keep the SOFC fuel utilization rate at 0.8, and the system output power is shown in figure 6. As can be seen from figure 7, under the same current density and working pressure, the system efficiency of the preheater before the turbine is reduced by 1% to 2% compared with the system efficiency of the preheater after the turbine.

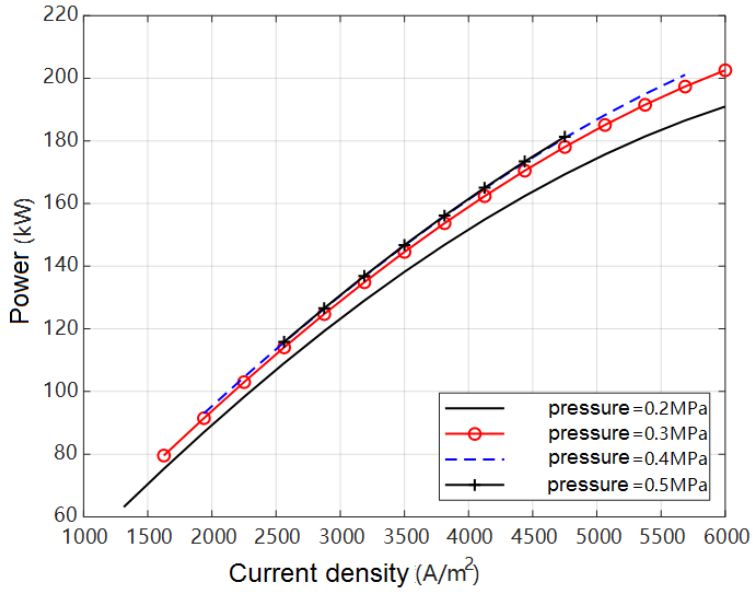
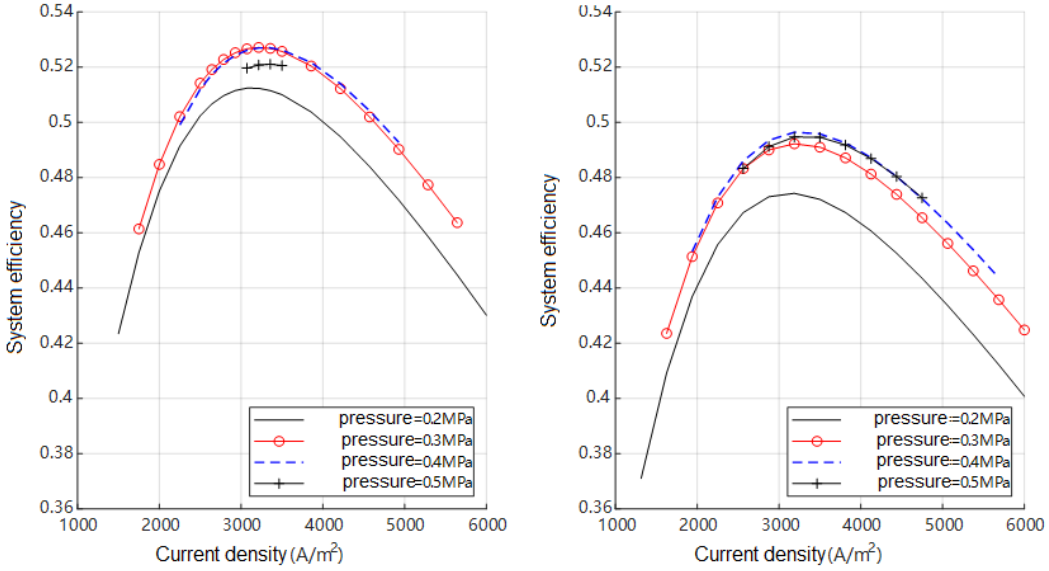


Figure 6. Current density-power characteristic curve of low temperature fuel cell system



(a) Preheater after turbine (b) Preheater in front of turbine

Figure 7. Current density-efficiency characteristics of low temperature fuel cell systems

4. Conclusion

The temperature increases with the increase of fuel flow, which is related to the characteristics of the SOFC. The lower the efficiency, the more heat is generated inside the SOFC, the lower the SOFC inlet temperature requirements, the lower the power of the preheater, and the lower the temperature drop of the exhaust gas. As the operating pressure of the SOFC rises, the compressor outlet temperature increases, the power requirements of the preheater in front of the turbine and the exhaust gas temperature decreases. The characteristics of a combined cycle system in which the preheater is placed in front of the turbine are closely related to the performance of the fuel cell. The turbine inlet temperature of low-temperature SOFC/GT has little correlation with operating conditions and pressure of low-temperature SOFC. The temperature shows a downward curve with the change in fuel flow, which is related to the characteristics of the SOFC, as the operating pressure of the SOFC increases, the turbine decrease in inlet temperature drop. The low-temperature SOFC/GT cycle maintains high-efficiency design conditions with a fuel utilization rate of 0.8-0.85, and the highest efficiency is about 52%. The design working pressure of the medium temperature SOFC/GT cycle is suggested to be 0.4MPa-0.5MPa, and the system efficiency will be higher than 50% when the compression ratio is at 0.8-0.85, and the maximum efficiency is about 64%.

Acknowledgement

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References

[1] Singhal S C, Kendall K. High-temperature solid oxide fuel cells: fundamentals, design and applications [M]. Elsevier, 2003.

[2] Leah R T, Bone A, Hammer E, et al. Development Progress on the Ceres Power Steel Cell Technology Platform: Further Progress Towards Commercialization [J]. ECS Transactions, 2017, 78（1）: 87-95.

[3] Yousri M. A. Welaya, M. Mosleh, Nader R. Ammar. Thermodynamic analysis of a combined gas turbine power plant with a solid oxide fuel cell for marine applications[J]. International Journal of Naval Architecture and Ocean Engineering,2013, 5(4): 529-545.

[4] .Leah R T, Brandon N P, Aguiar P. Modelling of cells, stacks and systems based around metal-supported planar IT-SOFC cells with CGO electrolytes operating at 500–600°C[J]. Journal of Power Sources, 2005, 145（2）: 336-352.

[5] Cengel Y A, Boles M A. Thermodynamics: an engineering approach [M]. New York: McGraw-Hill Education, 2014.