Experimental and Numerical Studies of a Recuperator in Micro Turbines

Xusheng Shi[1, 2], *Yongwei* Wang[1, 2*], and *Xiulan* Huai[1, 2**]

[1] Institute of Engineering Thermophysics, Chinese Academy of Sciences, Beijing, 100190, China
[2] University of the Chinese Academy of Sciences, Beijing, 100049, China

Abstract. In this paper, a recuperator model is established to simulate the real working state of the recuperator in the micro turbine. The relative error between simulated and experimental data doesn't exceed 5%, which indicates that the model can better reflect the changing law of the recuperator performance. Therefore, the recuperator model proposed in this paper is reasonable and reliable. In addition, the simulation results indicate that heat transfer efficiency is not sensitive to the change of hot inlet temperature, however, it increases with the decrease of mass flow rate. On the other hand, the decrease of inlet mass flow leads to the relative pressure loss decreased on hot and cold sides.

1. Introduction

Micro turbines have been widely used in oil and gas industry, power generation and other fields because of their advantages of simple and compact structure and low pollution. The adoption of efficient recuperated cycle technology can greatly improve their thermal efficiency to meet economic requirements [1]. The compact and efficient recuperator is one of the key equipments in micro turbines.

Many scholars have done a lot of work on the development of recuperator performance simulation and optimization. Xiao et al.[2] reviewed the types, materials, manufacturing, operating characteristics and performance optimization of recuperator. Wang et al.[3] reviewed the development and application of several high-efficiency surface heat exchangers. Dong et al.[4] obtained the heat transfer and pressure loss correlations of the wavy fin and flat tube heat exchangers by experiments. Do et al.[5] experimentally investigated the pressure drop and heat transfer characteristics of a recuperator with offset strip fins and proposed two analytical models to predict the pressure drop and heat transfer characteristics of the fabricated recuperator. Kim et al.[6] refined the recuperator characteristic models improved simulation accuracy.

At present, the performance analysis of micro turbines usually adopts the general recuperator simulation model rather than the accurate performance based on the experiment. The general model ignores the anisotropy of the recuperator geometry and heat exchange unit, and it does not fully consider the important factors affecting the recuperator performance, and lacks of experimental correction. Therefore, it cannot truly reflect the performance change law of the micro turbine recuperator.

In view of the shortcomings of the above research, the performance of recuperator will be studied experimentally in this paper. And the numerical model was established. The numerical simulation results are compared with the experimental results to prove the correctness of the model. Then the performance of recuperator under different operating conditions is studied.

2. Recuperator and experiment rig

2.1 Recuperator

The recuperator in this paper is a plate heat exchanger, which has compact structure and high heat exchange efficiency. The structure of cold and hot channels is shown in Fig. 1.

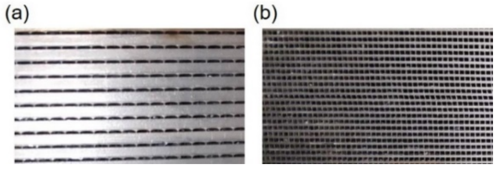

Fig. 1. Cold and hot channels of plate heat exchanger.

2.2 Experiment rig

The recuperator experiment test rig is shown in fig. 2, which includes recuperator test pieces, air system, heating system and measurement system, etc. Due to the

*Corresponding author's e-mail: wangyongwei@iet.cn
**Corresponding author's e-mail: hxl@iet.cn

coupling of pressure and flow rate of fluid, solenoid valve and back pressure valve in the air system need to be adjusted simultaneously during the experiment to obtain the required flow rate and pressure. And the power of electric heater in the heating system should be adjusted, so as to simulate the real working condition of micro turbine recuperator. In addition, the blower in the air system provides low-pressure air for the hot side to simulate the gas turbine outlet flow; the air compressor provides high pressure air to the cold side to simulate the compressor outlet flow. The measured system parameters are shown in table 1.

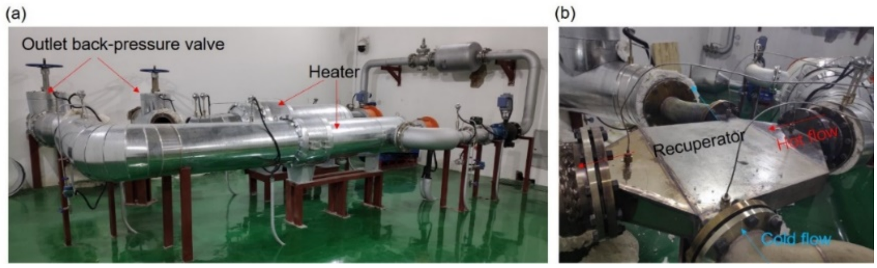

Fig. 2. Recuperator experiment test rig.

Table 1. Recuperator test rig measurement system

Measured parameters	Measuring equipment	Accuracy/%	Number	Range
Temperature (before heating)	Pt1000	±0.2	2	0~100℃
Temperature (after heating, cool flow)	Pt1000）	±0.2	1	0~300℃
Temperature（cool flow inlet）	Pt1000	±0.2	1	0~300℃
Temperature（cool flow outlet）	K type Thermocouple	±0.75	1	0~800℃
Temperature（after heating, hot flow）	K type Thermocouple	±0.75	1	0~800℃
Temperature（hot flow inlet）	K type Thermocouple	±0.75	1	0~800℃
Temperature（hot flow outlet）	K type Thermocouple	±0.75	1	0~800℃
Pressure（cool flow）	Pressure transmitter	±0.2	3	0~0.5MPa
Pressure（hot flow）	Pressure transmitter	±0.2	3	0~0.1MPa
Mass flow	Gas turbine meter	±1.5	2	65m^3/h~1300m^3/h

3. numerical modeling

In this paper, Flownex SE (thermodynamic system simulation software) were used for the numerical modelling and simulation. The software is suitable for design and simulation of aerospace and other related industry thermodynamics and turbomachinery network problems. It has standard library components such as turbines, compressors, pipes, and heat transfer elements, which allows easy forming of turbomachinery networks and recuperator model. A Flownex user can analyze a standard turbomachine and add and analyze additional components. Figure 3 describes the Flownex recuperator model. The model consists of hot and cold inlet boundary properties, hot and cold channels, heat transfer elements, radiation to the environment and outlet boundary conditions. The connecting nodes in the network system join the network elements smoothly and ensure good network communication between the elements.

In order to verify the correctness of the model, the simulation results are compared with the experimental results, as shown in Table 2. Simulation results indicate that the relative error between simulated and experimental data doesn't exceed 5%. The correctness and validation of the simulation model is demonstrated.

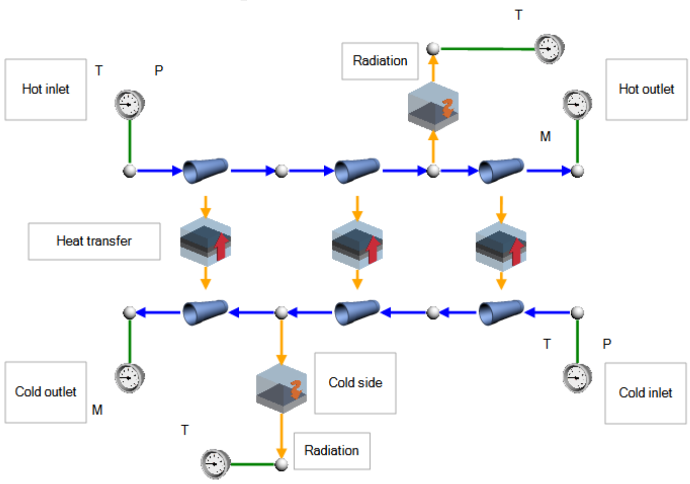

Fig. 3. Flownex SE recuperator model.

Table 2. The correctness and validation of the simulation model

	experimental result	simulated result	relative error
Mass flow (hot)	0.205kg/s	0.205kg/s	-
Inlet temperature (hot)	564.3℃	564.3℃	-
Inlet pressure (hot)	112.45kPa	112.45kPa	-
Temperature difference between inlet and outlet (hot)	173.5℃	177.4℃	2.25%
Pressure difference between inlet and outlet (hot)	0.96kPa	0.961kPa	0.1%
Mass flow (cold)	0.128kg/s	0.128kg/s	-
Inlet temperature (cold)	304.3℃	304.3℃	-
Inlet pressure (cold)	383kPa	383kPa	-
Temperature difference between inlet and outlet (cold)	225.5℃	222.08℃	1.52%
Pressure difference between inlet and outlet (cold)	26.14kPa	25.78kPa	1.38%

4. Results and discussion

The heat transfer efficiency is defined as:

$$\varepsilon = \frac{T_{\text{cool,out}} - T_{\text{cool,in}}}{T_{\text{hot,in}} - T_{\text{cool,in}}} \tag{1}$$

where $T_{\text{hot,in}}$, $T_{\text{cool,in}}$ and $T_{\text{cool,out}}$ are hot flow inlet temperature, cold flow inlet temperature and cold flow outlet temperature, respectively.

The relative pressure loss of hot side is calculated as:

$$\delta p_{\text{hot}} = \frac{p_{\text{hot,in}} - p_{\text{hot,out}}}{p_{\text{hot,in}}} \times 100\% \tag{2}$$

where $p_{\text{hot,in}}$ and $p_{\text{hot,out}}$ are hot flow inlet pressure and hot flow outlet pressure, respectively.

The relative pressure loss of cold side:

$$\delta p_{\text{cold}} = \frac{p_{\text{cold,in}} - p_{\text{cold,out}}}{p_{\text{cold,in}}} \times 100\% \tag{3}$$

where $p_{\text{cold,in}}$ and $p_{\text{cold,out}}$ are cold flow inlet pressure and cold flow outlet pressure, respectively.

Figure 4 shows the effect of hot flow inlet temperature ranging from 480 to 560°C on heat transfer efficiency and relative pressure loss of hot and cold side. It can be seen that heat transfer efficiency is not sensitive to the change of hot inlet temperature. This is because the structure and working medium of the recuperator are fixed, the changing of hot flow inlet temperature can't improve the heat transfer coefficient of hot and cold sides. In addition, the relative pressure loss of the cold side remained unchanged, while the hot side increased with the increase of the hot flow inlet temperature.

Figure 5 shows the effect of mass flow rate ranging from 0.1 to 0.3kg/s on heat transfer efficiency and relative pressure loss of hot and cold side. It can be seen that heat transfer efficiency increases with the decrease of mass flow rate. In addition, the decrease of inlet mass flow leads to the relative pressure loss decreased on both sides.

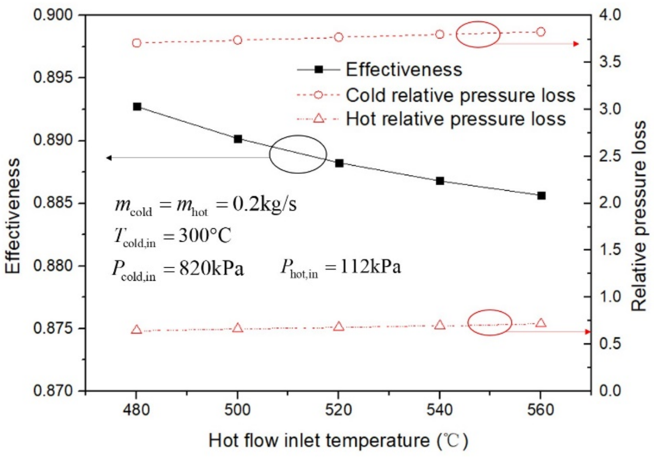

Fig. 4. Effect of hot flow inlet temperature.

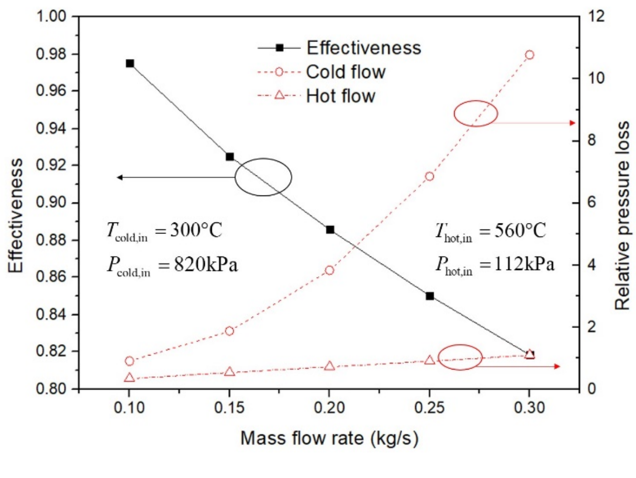

Fig. 5. Effect of inlet mass flow rate.

5 Conclusion

In this paper, the recuperator model is established to simulate the real working state of the recuperator in the micro turbine. The relative error between simulated and experimental data doesn't exceed 5 %, which indicates that the model can better reflect the changing law of the recuperator performance. Therefore, the recuperator model proposed in this paper is reasonable and reliable. In addition, the simulation results indicate that heat transfer efficiency is not sensitive to the change of hot inlet temperature, however, it increases with the decrease of mass flow rate. On the other hand, the decrease of inlet mass flow leads to the relative pressure loss decreased on hot and cold sides.

This study was supported by the Key Research Program of the Chinese Academy of Sciences (ZDRW-CN-2017-2).

References

1. C.F. McDonald. Appl Therm Eng. **23**, 1463-1487 (2003).
2. G. Xiao, T. Yang, H. Liu, D. Ni, M.L. Ferrari, M. Li, et al. Appl Energy. **197**, 83-99 (2017).
3. Q. Wang, M. Zeng, T. Ma, X. Du, J. Yang. Appl Energy. 135, 748-777 (2014).
4. D. Junqi, C. Jiangping, C. Zhijiu, Z. Yimin, Z. Wenfeng. Appl Therm Eng. **27**, 2066-2073 (2007).
5. K.H. Do, B.-I. Choi, Y.-S. Han, T. Kim. Int J Heat Mass Transfer. **103**, 457-467 (2016).
6. M.J. Kim, J.H. Kim, T.S. Kim. Appl Therm Eng. **108**, 122-130 (2016).