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Performance evaluation of parallel thermoacoustic refrigerator
並列熱音響冷凍機の性能評価

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1. Introduction

Thermoacoustic effects are observed when heat energy is converted into acoustic waves. A system which achieves energy conversion of heat into sound waves is called a thermoacoustic engine (prime mover [PM]). A system which achieves the energy conversion of sound waves into a heat flow is called a thermoacoustic refrigerator (heat pump [HP]). For energy conversion devices, both the prime mover and the heat pump are composed of stacks of narrow tubes in which the acoustic waves propagate. In the prime mover, sound waves are generated when one side of the stack is heated by high-temperature heat. In the heat pump, one side of the stack is cooled when sound waves propagate through the stack. This thermoacoustic refrigerator presents many advantages: it can make use of unused energy such as solar heat or industrial waste heat because its driving source is heat. It is respectful to the environment because it requires no hazardous refrigerant. Moreover, it is inexpensive because it has a simple structure with no moving parts. However, it has not been applied because of its high driving temperature (300 °C over) or low cooling performance. A more practical use of the thermoacoustic system requires low-temperature driving and a high-efficiency drive.

Some reports describe that a cascade thermoacoustic system can be driven by a low onset temperature ratio[1)]. Biwa et al. achieved an onset temperature ratio of 1.19 using a cascade thermoacoustic engine with five regenerators[2)]. However, some problems remain. One is that the energy conversion efficiency is lower because it becomes difficult to set up all stacks in positions where the acoustic impedance is high. A second difficulty is that the high heat exchanger between the prime movers heats up the low-temperature section of the prime mover which decreases its output over time. We proposed a parallel thermoacoustic engine, which is expected to be driven with high efficiency because it can set up two stacks in the high impedance part. Furthermore, the system can heat up two stacks with a single heat source. Therefore, this new system provides a solution to the above-mentioned difficulties. Previous studies confirmed that the parallel thermoacoustic engine can be driven by lower temperature and higher energy conversion efficiency. In this study, we evaluated the cooling capacity of a parallel thermoacoustic refrigerator.

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2. Experimental system

When sound waves propagate through the narrow tubes, energy transfer from the work flow to the heat flow occurs. When sound waves generated in the PM-Stack propagate through the HP-Stack, a heat pump effect occurs due to the energy conservation law between work flow and heat flow. For the heat pump effect to occur effectively, it is necessary to set up a HP-Stack at a position where the acoustic impedance is high. When volume velocity is the smallest in the HP-Stack, it is possible to drive it with high efficiency in the system because reduced viscous dissipation is reduced

Figure 1 and 2 show a parallel and cascade thermoacoustic refrigerator with two prime movers. The cooling temperatures of the three thermoacoustic refrigerators including a single thermoacoustic refrigerator are compared. The high temperature part of the PM stack is defined as the origin. The HP-Stack is set up in a position where it is 1.35 m from the origin in a counterclockwise direction. The Phase adjuster (PA) is set up a position where it is 0.9 m from the origin in a counterclockwise direction. A gas mixture of helium and argon (1:1) is filled in each system. In a single thermoacoustic refrigerator, heat power of 330 W is input to PM-Stack. In a cascade thermoacoustic refrigerator, heat powers of 165 W are input to each PM-Stack. In a parallel thermoacoustic refrigerator, heat power of 330 W is input to two PM-Stacks. Heat power of 330 W is input to each system.

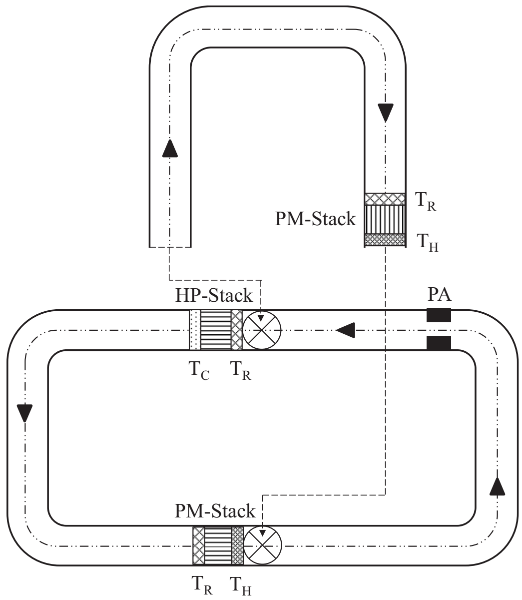

Fig. 1. Diagram of the parallel thermoacoustic refrigerator.

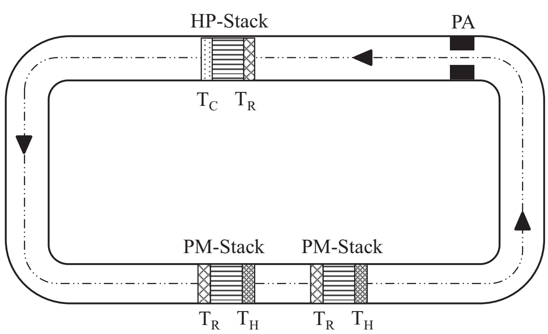

Fig. 2. Diagram of the cascade thermoacoustic refrigerator.

3. Results and considerations

Figure 3 shows the temperature profiles of the HP-Stack over time after the PM-Stack in each system was heated. The cooling temperatures (T_C) of a single, parallel and cascade thermoacoustic refrigerators were -5.4°C, -12.1°C and -6.9°C. The sound intensity was calculated using a wave equation applied to Rott's acoustic approximation. Amplified sound intensities (I_{PM}) of single, parallel and cascade thermoacoustic refrigerators are 2.82 kW/m, 3.40 kW/m, and 1.27 kW/m. Dissipated sound intensities (I_{HP}) of single, parallel and cascade thermoacoustic refrigerator are 1.16 kW/m, 1.29 kW/m, and 0.56 kW/m. In parallel thermoacoustic refrigerators, it is thought that the energy generation capacity is higher at the PM-Stack than in single or cascade thermoacoustic refrigerators and the cooling performance is higher because the PM-Stacks can set up at high acoustic impedance positions.

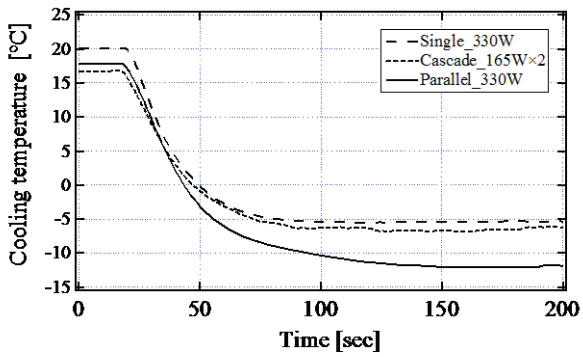

Fig. 3. Temperatures of the HP-Stack in three thermoacoustic refrigerators

Acknowledgments

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