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Use of Heat Transfer Fluids to Drive a Loop-Tube-Type Multistage Thermoacoustic System with Two Diameter-expanded Prime Movers

内径拡大プライムムーバーを持つループ管方式多段熱音響システムの伝熱流体による駆動

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1. Introduction

Thermoacoustic phenomena have potential applications to thermal energy systems, i.e., heat engines and heat pumps.[1)] Thermoacoustic prime movers are heat engines converting thermal energy into mechanical energy of working gas, namely acoustic energy. For practical use, resulting acoustic energy is converted into electrical energy, or is directly used for thermoacoustic refrigeration. Such thermal energy systems utilizing thermoacoustic effects are called as thermoacoustic systems. We have studied a loop-tube-type thermoacoustic system with multistage diameter-expanded prime movers. Experimental system with simply two diameter-expanded prime movers in the looped tube shows that adjusting the placement of two prime movers results in the onset of thermoacoustic oscillation at relatively low temperature, namely 67°C for high-temperature side and 20°C for low-temperature side.[2)] This result is promising for the utilization of low-temperature heat sources such as solar-heated water; however, prime movers of the experimental system utilized pseudo heat sources by coiled electric heaters in the tube. In this study, heating working gas in the thermoacoustic system with two-stage diameter-expanded prime movers by using heat exchangers and heat transfer fluid instead of electric heaters is evaluated.

2. Experimental

2.1. Experimental system

A brief schematic of the experimental setup for evaluation of a thermoacoustic system with two diameter-expanded prime movers is shown in **Fig. 1**. This thermoacoustic system is made of stainless steel tubes. The diameter-expanded prime movers, A and B, are identical, which have the tube length of 0.33 m and inner diameter of 100 mm; the inner diameter of tubes connecting prime movers are 42.6 mm. The total tube length of the looped tube is 5.12

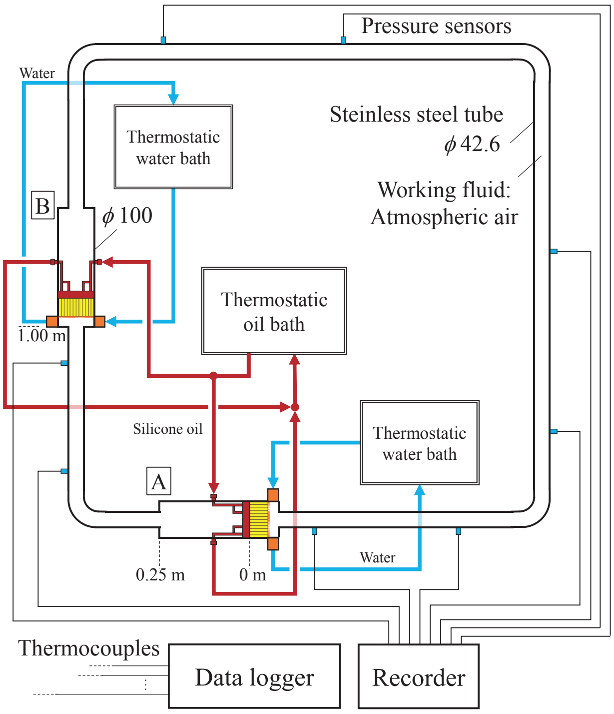

Fig. 1 Experimental setup

m. The spacing of two diameter-expanded prime movers are 0.75 m, at which the previous study confirmed the lowest onset temperature. The working gas is air at atmospheric pressure. Each prime mover has a stack (ceramic honeycomb, 900 channel/in^2, axial length of 0.05 m, and outer peripheral wall diameter of 94 mm) and hot- and cold-side heat exchangers sandwiching the stack. The circulating water at the room temperature (26°C) is supplied from a thermostatic bath to the cold-side heat exchanger exhausting excess heat through its thin comb-shaped fins in the tube. The hot-side heat exchanger is a fin-tube one, to which a high-temperature silicone oil is supplied. Fins of the hot-side one have length of about 0.02 m and thickness of 0.5 mm. Hot-side heat exchangers of both prime movers receive oil from a heating thermostatic bath (Huber, CC-304B).

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2.2. Temperature and sound measurements

Experimental evaluations were performed varying the setting temperature of the thermostatic oil bath. Temperatures of several points in prime movers and sound pressures in connecting tubes were measured by K-type sheathed thermocouples and pressure sensors (PCB Piezotronics, model 112A21), respectively. Measured temperatures were inlet and outlet oil temperatures for hot-side heat exchangers, fin temperature of the hot-side heat exchanger, gas temperatures at hot- and cold-side ends of the stack, and the inlet water temperature for cold-side heat exchangers. Gas temperatures were measured on the central axis of tubes.

3. Results and Discussion

The experiment evaluation were started by heating the thermostatic oil bath from the room temperature to the setting value of 120°C circulating fluids. Thermoacoustic gas oscillation occurred spontaneously during temperature rising. Time valuations of measured temperatures and sound pressure measured at the position of 2.48 m from the hot-end of the stack in the prime mover A are shown in **Fig. 2**. Results show that the amplitude of sound pressure increased more than 100 Pa when hot-end gas temperatures of stacks increased over 78°C. After the temperature stabilization, the setting temperature of the thermostatic oil bath decreased stepwise at a 5 K interval with waiting the temperature stabilization for each step. The thermoacoustic oscillation continued at the setting temperature of 115°C and 110°C; however, the oscillation disappeared during the step to 105°C. In addition, setting again to 110°C resulted in a regeneration of thermoacoustic oscillation. **Table 1** shows measured temperatures at steady states for each setting temperature of oil bath. This indicates that the experimental system requires the inlet oil temperature of at least 108°C for thermoacoustic oscillation and the necessary temperature ratio of fluids is 1.27. This result is worse than that of the previous study, namely temperature ratio of 1.16 (67°C and 20°C). This degradation should be caused only by hot-side heat sources, namely electric heaters in the previous study and fin-tube heat exchanger in this study. Ignoring the performance of hot-side heat exchanger, the necessary gas temperature ratio between hot- and cold-end of the stack is at least 1.19 (91.3°C against 34.0°C). This ratio is also slightly worse than the previous value. It is probable that the acoustic dissipation by fin and tubes of the hot-side heat exchanger is significant. In addition, cold-side heat exchangers does not seem to have enough performance to maintain cold-side gas temperature low.

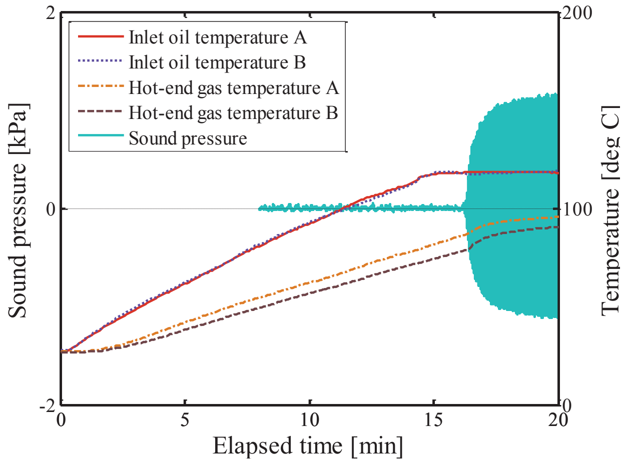

Fig. 2 Temperatures and sound pressure

Tab. 1 Steady-state temperatures [°C]

Oil bath setting		120	115	110	105
Oil inlet	A	117.9	112.9	108.0	103.2
	B	119.3	114.3	109.4	104.4
Oil outlet	A	116.7	112.0	107.4	102.6
	B	116.6	112.0	107.4	102.6
Hot-end gas	A	97.8	95.2	91.3	86.1
	B	92.7	91.2	87.6	81.8
Cold-end gas	A	35.1	34.3	34.0	34.2
	B	36.7	36.2	35.7	36.7
Water inlet	A	26.3	26.4	26.4	26.5
	B	26.5	26.5	26.5	26.6
Oscillation		yes	yes	yes	no

4. Conclusions

The use of heat transfer fluids and heat exchangers for driving the thermoacoustic system with two diameter-expanded prime mover was evaluated in experiments. Necessary temperature ratio for the onset of thermoacoustic oscillation was confirmed at least 1.27 for inlet fluid temperatures, and at least 1.19 for gas temperatures in the stack. These results demonstrate the practical possibility of utilizing low-temperature heat sources.

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