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Mechanism of the heat exchange promotion by superimposing the external sound wave in standing-wave thermoacoustic system
定在波型熱音響システムにおける外部重畳音波による熱交換促進メカニズム

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1. Introduction

To practically use a thermoacoustic system, the improvement of conversion efficency necessary. The technique to heat the interior of the stack has ever been proposed for more efficient thermal conversion[1]. In previous paper, intending the enhancement of the energy conversion efficiency by superposing acoustic vibrations on the oscillating sound field in the working fluid of the system, the promotion of the thermoacoustic conversion phenomenon has been confirmed[2]. However, this mechanism has not been examined in detail yet. This report focuses on the heat exchange area as the index of the heat exchange environment in the stack to investigate the factors that improve the energy conversion efficiency when using external sound waves in a standing-wave thermoacoustic engine.

Installing a loudspeaker in the system at the end as the source of the externally superposing sound wave, the experiment was carried out.

2. Experiments

The schematic of the experimental system is shown in Fig. 1. A straight-tube thermoacoustic system of a 2000 mm total length and a 42 mm inner diameter is constructed. The one end is closed and a loudspeaker (TOA Co., TU-750) is set at another end. A new coordinate whose origin (x=0) locates at the vibrating surface of the loudspeaker of the left end is settled as illustrated in the figure. The working fluid is atmospheric air. A honeycomb ceramics with flow path radius of 0.55 mm and length of 50 mm is used for the stack whose cold end locates at x=1500 [mm]. By setting an ordinary temperature heat exchanger (circulating water) at one end of the stack (x=1500 [mm]) as well as a high-temperature heat exchanger (an electric heater) at another end (x=1550 [mm]), the temperature difference is given between both ends of the stack. The input to the heater is kept constant at 300 W. The system shows a stable self-exited vibration at the resonance frequency with half wavelengths of full tube length. From the loudspeaker, the continuous sinusoidal sound wave is supplied to

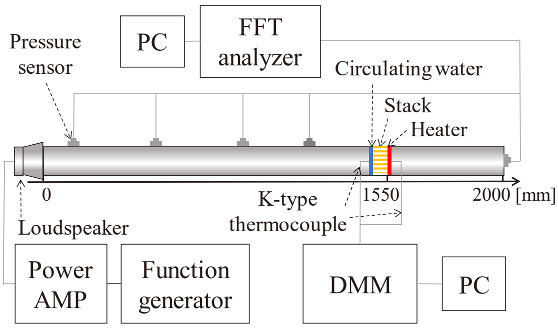

Fig.1 Experimental setup.

the system with a stable self-excited sound. Five conditions for the input electric power to the loudspeaker of 2.5, 5.0, 8.8, 12.5 and 17.2 W are examined. When the thermal equilibrium is attained at each condition of the loudspeaker input, the temperatures at both ends are measured with K-type thermocouples. In addition, the sound pressure in the system is measured with the crystal-type pressure sensor (PCB Co., 112A21) set at x=150, 450, 850, 1950 and 2000 [mm].

Work flow I [W/m^2] at each condition is evaluated by the following equation.

$$I = \frac{1}{2}|p||u|\cos\phi, \quad (1)$$

where p is the sound pressure, u is the particle velocity, and ϕ is the phase difference between the sound pressure and the particle velocity. In the present study, the difference ΔI of the work flow between the hot end and the cold end of the stack is defined as the generation of the work flow in the stack.

3. Results and discussions

The variations of the temperatures at both ends of the stack for various loudspeaker input conditions are listed in Table 1. Furthermore, the work flow generation for each input power to the loudspeaker shown in Fig. 2 classified to three components; the red line realized only by a thermal input, the white circle calculated by adding input from the loudspeaker with no thermal input to the red line and the red circle realized by adding input from the loudspeaker to the self-excited sound. It is clearly confirmed that the work flow generation is increased when superimposing the external sound on the self-excited sound. When the external sound is increased, the temperature difference between both ends of the stack decreases. It is supposed that the thermal energy stored in the stack as the temperature is converted to the sound energy due to the promotion of the heat exchange.

In order to clarify this effect, the heat exchange area is focused on. The heat exchange area S that can contribute to the heat exchange in the cross section of the stack is considered as the index of the heat exchange in the system. S is calculated using the thicknesses of the viscous boundary layer and the heat boundary layer. S in the cross section of the stack calculated on the base of the calculation result for the thicknesses of the boundary layers is shown in Fig. 3. Here the value of S is one averaged over the whole stack area. It is found that S is extended by the superimposing external sound. The change of the temperatures at ends of the stack is considered as the contributing factor here. The reason is that each of the dynamic viscosity coefficient, the thermal diffusion coefficient included in the thicknesses of thermal and viscous boundary layers as the variables depending on the temperature. Namely, with the temperature at the ends of the stack decrease, the enlargement of S is assumed to occur by the reduction of the thicknesses of the thermal and viscous boundary layers in the state to keep the condition that the thermal boundary layer is thicker than the viscous boundary layer. Regarding the result of the decrease in the heat exchange area for 17.2 W, the effect of heat flow in the stack is controversial. As a result, it is supposed that the change of the heat exchange area has similar trend the work flow generation against the loudspeaker input. Therefore, it is suggested that the superimposing external sound expands S and improves the heat exchange environment.

4. Conclusion

In this report, we investigated the factors that improve the energy conversion efficiency by superimposing the external sound wave on standing wave thermoacoustic system. As a result, after the chained process such as the promotion of the thermoacoustic phenomenon, the temperature lowering of the working fluid in the stack, the reduction of the thicknesses of the boundary layers and the growth of the heat exchange area, the loudspeaker input is assumed to have an effect to induce a cycle starting with further promotion of the thermoacoustic phenomenon.

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Table 1 Temperature change at both ends of stack.

Loudspeaker input [W]	T_c [℃]	T_h [℃]
0.0	88	611
2.5	106	539
5.0	120	482
8.8	131	432
12.5	137	411
17.2	138	393

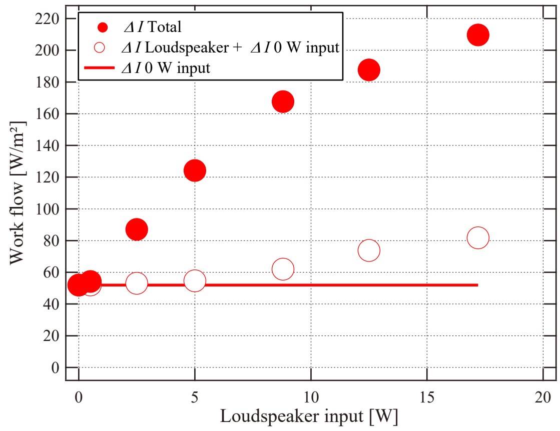

Fig.2 Each component of work flow in stack.

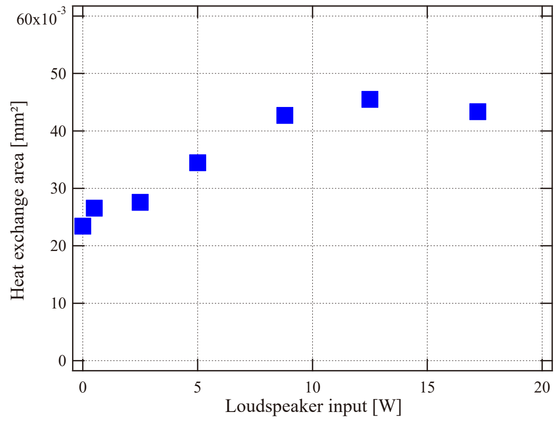

Fig.3 Change of heat exchange area by superposition of external sound waves.

Acknowledgment

This work was partly supported by JSPS grants-in-aid for young scientists (A) and (B), JSPS grant-in-aid for challenging exploratory research, grant-in-aid for scientific research (C), program for fostering regional innovation and JST super cluster program.

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