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Advancement of energy conversion in traveling-wave thermoacoustic-system by heating the center of a stack

進行波型熱音響システムにおけるスタック中央加熱によるエネルギー変換促進

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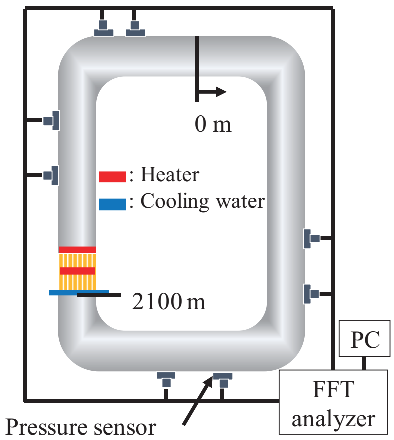
1. Introduction

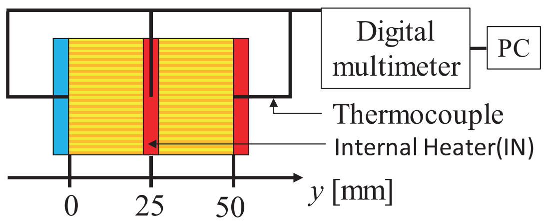
In the conventional study on thermoacoustics, only the temperatures at both ends of the stack have been taken into account and the temperature distribution in the stack has never been considered[1,2]. However, since the thermoacoustic phenomenon is induced by the volume fluctuation due to the thermal expansion or compression during the motion of the fluid along the temperature gradient[3], the temperature distribution in the stack is assumed to affect the energy conversion. Further, only one side of the stack is generally heated[1,2]. However, since the temperature gradient is weighted near the hot end of the stack, the contribution of the cold-end side to the energy conversion is assumed to be small. In this report, considering the temperature in the stack, by making the temperature gradient form also near the cold end of the stack with another heat source added to the center, the energy conversion in the whole stack is attempted to realize. Furthermore, the influence of the temperature distribution in the stack on the energy conversion is evaluated with the work flow generation.

2. Experiments

The system for the experiment is shown in **Fig. 1(a)**. A clockwise coordinate x is set in the system. A traveling-wave thermoacoustic-system with a 3300 mm total length and a 42 mm inner diameter is used. The working fluid is atmospheric air. The stack of honeycomb ceramics with a 0.35 mm flow path radius and a 50 mm length is set at x = 2100 mm. The schematic of the stack is shown in **Fig. 1(b)**. By settling a cold heat-exchanger at one side (y = 0 mm) and an electric heater at another end (y = 50 mm) of the stack, the temperature difference is given between both ends. Further, by uniformly warming the interior of the stack with an electric heater set on the cross-section at the center (y = 25 mm), the temperature T_N at the center of the stack is adjusted. To examine the influence of the temperature distribution in the stack on the energy conversion, T_N is increased while adjusting the electric heater and the cold heat exchanger so that the temperatures T_H at the hot end and T_C at the cold end are kept at 278 °C and 35 °C, respectively. The temperatures T_H, T_C and T_N are measured with K-type thermocouples and the sound pressure in the tube is observed with the pressure sensors (product of PCB Co.).



(a) Whole system



(b) Stack

Fig. 1. Schematic of experimental system.

3. Results

The temperature distribution in the stack is shown in **Fig. 2** for every condition. The lowest value of T_N appears under the condition without heating the center of the stack. T_N is raised from 120 °C to 330 °C by heating the center of the stack. The generation of sound is confirmed for every T_N. Using the transfer matrix method, the work flow in the tube is calculated with the measured sound

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pressure.[4] The work flow means the amount of energy passing through unit cross-sectional area per unit time in the sound field[5], expressed by

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

where p is the sound pressure, u is the particle velocity, φ is the phase difference between p and u. The difference of the work flow between the hot end and the cold end is defined as the work flow generation ΔI. The relation between T_N and ΔI is shown in **Fig. 3**. ΔI increases with T_N in the range $T_N \leq 162$ °C, hardly changes in the range 180 °C $\leq T_N \leq$ 240 °C, and decreases against T_N in the range $T_N \geq 260$ °C.

4. Discussion

The influence of heating the center of the stack on the energy conversion is discussed. As described above, ΔI changes with the temperature distribution in the stack. As well known, the energy conversion from heat to sound is proportional to the temperature gradient[3]. As seen in Fig. 2, in the case without heating of the center of the stack, the temperature gradient is weighted at the hot-end side. Then the energy conversion is assumed to take place weighted at the hot-end side. Figure 2 also demonstrates that, as T_N increase, the weighting of the temperature gradient of the stack shifts from the hot-end side to the cold-end side. When $T_N \leq 240$ °C, since the temperature gradient increases at the cold-end side due to heating the center of the stack, the energy conversion at the cold-end side is advanced. As the result, ΔI is supposed to increase because the energy conversion takes place in the whole stack. On the other hand, when the center of the stack is heated too much, the temperature gradient at the hot-end side becomes gradual. Then, because of the energy conversion weighted at the cold-end side, ΔI is supposed to decrease.

5. Conclusion

To advance the energy conversion, the influence of the temperature distribution in the stack on the energy conversion was examined. Setting an electric heater at the center of the stack as well, the experiment to actively change the temperature distribution in the stack was carried out. As a result, the work flow generation in the case of heating the center of the stack was confirmed to increase around 1.6-fold, comparing with the case without heating the center of the stack. The cause is supposed that the energy conversion takes place in the whole system when the temperature gradient is formed also at the cold-end side of the stack due to heating the center of the stack. Thus, the validity of heating the center of the stack for advancing the energy conversion was suggested.

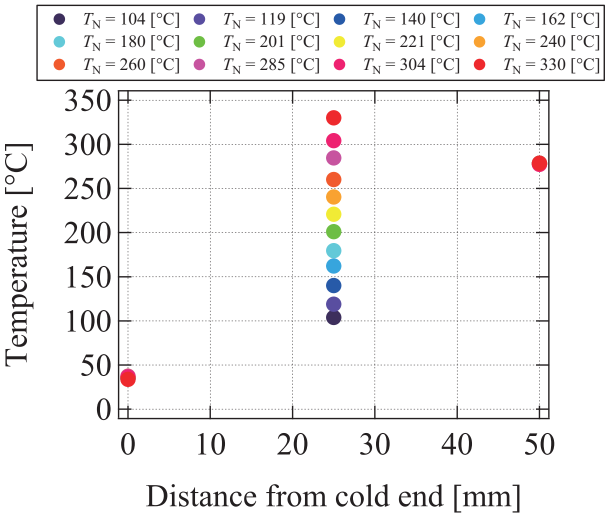

Fig. 2. Temperature distribution in the stack.

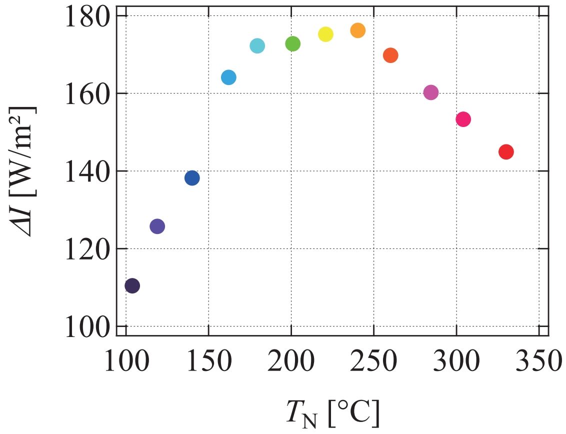

Fig. 3 Relationship between T_N and ΔI.

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