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Improvement of energy conversion efficiency of thermoacoustic system by heating stack inside

スタック内加熱による熱音響システムのエネルギー変換効率改善

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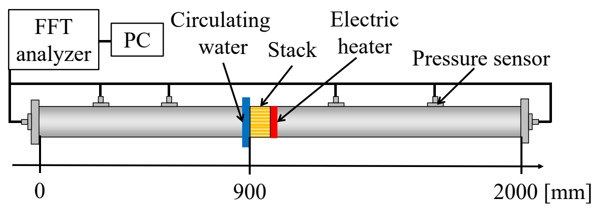
1. Introduction

In order to realize a thermoacoustic system, the research for improving its energy conversion is required. The techniques to improve the efficiency have been reported much[1,2]. However the detailed mechanism of the stack, that is the key device for the thermoacoustic system, is scarcely known. Clarification of such a process may result in the enhancement of the energy conversion efficieny of the whole system. The mutual interaction with the heat flux due to the heated stack and the distribution of the temperature gradient in the stack are focused here. The current method to heat only one end of the stack makes the temperature gradient eccentrically distribute near the hot end and therefore only a part of the stack works for enegy conversion. Hence, by heating the stack inside, the production of the temperature gradient more active for the whole stack is examined as well as the control of the heat flow. Since the work flow is controlled by the heat flow, the control of the temperature gradient in the stack is assumed to be effective for realizing energy conversion with high efficiency. It has already been reported that, when the temerature is changed locally by setting a heater at the center of the stack for demonstrating the above, the work flow produced in the stack significantly changes with the temperature[3].

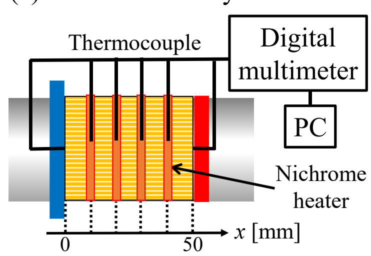
Then, in this paper, the influence of the heating position in the stack on the amount of the heat flow generation is experimentally investigated by selecting the heating position. Accounting the electric input power of the heater set on the cross-sectional surface in the stack, the energy conversion efficiency is also evaluated.

2. Experiments

The schematic of the system employed for the experiment is shown in **Fig. 1(a)**. A straight-tube type thermoacoustic system closed at both ends with a 2000 mm total length and a 42 mm inner diameter is used. The working fluid is atmospheric air. A honeycomb ceramics with a 0.55 mm flow path radius and a 50 mm length is used for the stack. The stack is set so that the hot end locates 950 mm distant from the left end of the system, that is 50 mm short of the node in the particle velocity distribution. The stack is illustrated in **Fig. 1(b)**. The circulating water and the hot heat-exchanger are arranged at one end at x=0 [mm] and another end at x=50 [mm], respectively. A spiral heater is used for the hot heat-exchanger (PM heater). The electric input power W_{PM} of the PM heater is kept constant at 330 W that satisfies the oscillation condition of the system. Further, nichrome wire heaters (internal heaters) are set at four positions (x=10, 20, 30, and 40 [mm]) and each cross-sectional surface is sequentially heated. The temperature at each center is measured with a K-type thermocouple. When the PM heater is switched on, the sound oscillation takes place and the temperature of each position slowly changes. A while later, attaining the equilibrium with the heat flux, the temperature becomes stable in about 20 min. The temperature at the heat equilibrium attained by the PM heater and the circulating water without driving any internal heaters is measured first as the reference. Then the temperature at the



(a) Schematic of system



(b) Schematic of stack

Fig. 1. Experimental system.

heat equilibrium for each input electric power W_I of the internal heater increases as 15, 40 and 60 W is measured after each equilibrium is attained in about 20 min. Furthermore, measuring the sound pressure and the resonance frequency in the tube with a crystal type pressure sensor (PCB Inc.), the work flow distribution is estimated from these data[5].

The work flow I [W/m^2] is calculated by

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

where p is the sound pressure, u is the particle velocity and ϕ is the phase difference between p and u[4]. In addition, the amount of work flow generation ΔI in the stack is defined as the difference of the work flow at the hot end of the stack from that at the cold end.

The energy conversion efficiency ε defined by

$$\varepsilon = \frac{\Delta I \times S}{W_{PM} + W_I} \qquad (2)$$

is evaluated in this paper. Here S is the sectional area of the tube.

3. Results and discussion

Under the condition of constant temperature ratio for both ends of the stack, W_I is changed for each internal heater. The sound oscillation is found under all the conditions at the resonance frequency with one wavelength corresponding to the total length of the system. The influence of heating with the internal heater on ΔI is paid attention now. The relation between W_I and ΔI at various heating positions is shown in **Fig. 2**. It is found that W_I increases with ΔI for all the heating positions. Furthermore, in the case of the heating position at x=20 [mm], ΔI most increases with W_I. Also in the case at x=30 [mm], ΔI almost equally increases. Next, the energy conversion efficiency accounting W_I is listed in **Table 1**. Here the energy conversion efficiencies for the cases heating at x=10, 20, 30 and 40 [mm] are denoted by ε_{10}, ε_{20}, ε_{30} and ε_{40}, respectively. Comparing with the case where only one end of the stack is heated, the additional heating of the stack inside realizes higher conversion efficiency. From these results, the heating of the stack inside is effective for enhancing the energy conversion efficiency and the heating near the center of the stack is suggested to maximize the heating effect.

4. Conclusion

In this experiment, by changing the heating position in the stack, the influence on the energy conversion efficiency was investigated. As a result, it was found that ΔI increased with W_I regardless of the heating position. However, the increment of ΔI depended on the heating position. ΔI most increased with W_I for the heating position near the center of the stack. Thus it was confirmed that the heating the inside of stack effectively controlled the heat flow and efficiently worked to enhance the energy conversion efficiency. Furthermore, the heating position to maximize the effect was suggested to be near the center of the stack.

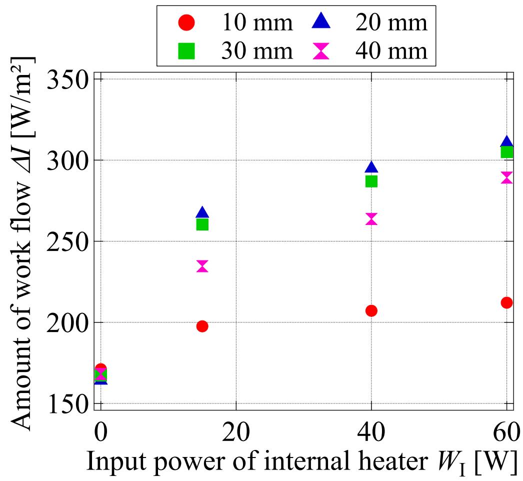


Fig. 2. Relations of W_I and ΔI for each condition.

Table 1. Energy conversion efficiency for each condition.

W_I [W]	ε_{10} (*10^{-3})	ε_{20} (*10^{-3})	ε_{30} (*10^{-3})	ε_{40} (*10^{-3})
0	0.718	0.689	0.702	0.706
15	0.793	1.07	1.05	0.945
40	0.779	1.11	1.09	1.00
60	0.755	1.11	1.10	1.04

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