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Effect of stack length variation on heat flow for miniaturization of thermoacoustic system

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1. Introduction

The events of mutual energy conversion and energy transport between heat and sound are called thermoacoustic phenomena[1-3]. A thermoacoustic system is expected to make effective use of unused heat by applying thermoacoustic phenomena. Thermoacoustic phenomena are generated by a device called a stack, which consists of many narrow tubes. Among thermoacoustic phenomena, the energy conversion from sound to heat is called the heat pump effect. One of the challenges to the practical application of a thermoacoustic system is that the system size is large several meters, which limits the range of practical use. We aimed to reduce the size of the system to expand its practical range.

In a previous study, the proper location of stacks in a forced-drive straight-tube thermoacoustic system was investigated. As a result of the study focusing on the dimensionless quantity $\omega\tau$ and the phase difference between sound pressure and particle velocity, it was confirmed that the installation position at which the cooling temperature reaches a maximum varies depending on $\omega\tau$[4-6].

In this study, we focused on the length of the heat pump stack and the resonance wavelength of the sound waves in the tube, which depends on the total length of the system. The total length of the system was varied, and the temperature difference between the two ends of the stack with respect to the length of the stack was measured at each total length[7]. The heat flow generated by the energy conversion was also studied.

2. $\omega\tau$

$\omega\tau$ is used as a dimensionless quantity that indicates the efficiency of the heat exchange between the fluid elements and the stack walls[4-6]. $\omega\tau$ is expressed by Eq. (1).

$$\omega\tau = 2\pi\frac{\tau}{T} = \omega\frac{r^2}{2\alpha} \qquad (1)$$

In Eq. (1), ω is the angular frequency of the sound wave, τ is the thermal relaxation time, T is the period of the sound wave, r is the channel radius of the stack, and α is the thermal diffusion coefficient of the fluid.

3. Experimental method

The stacks are made of stacked metal meshes whose length can be easily varied. The number of meshes used were 20 and 50 mesh. An overview of each metal mesh is shown in **Table I**. To make quantitative measurements of the heat pump stack, a forced-drive straight-tube thermoacoustic system consisting of a speaker and a thermoacoustic system was used. In addition, stacks were placed at locations where standing waves dominate and heat flow was measured[8].

An experimental system is shown in **Fig. 1**. The total length of the system at each number of meshes was derived using Eq. (1). In a tube where standing waves are dominant, the heat exchange is most efficient when $\omega\tau \sim \pi$. Under conditions of atmospheric air pressure (0.1 MPa) and constant temperature in the tube (297.15 K), the channel radius for each meshes was substituted into Eq. (1), respectively. The frequency was then derived by calculating the angular frequency ω such that $\omega\tau \sim \pi$. The frequency for 20 mesh was 73 Hz and 50 mesh was 520 Hz. The total length of the system is equal to one wavelength of sound waves. Quartz pressure sensors (PCB 112A21) were used to measure the sound pressure in the tube. K-type thermocouples (CHINO) were used to measure the temperatures at both ends of the stack.

The temperature difference between the two ends of the stack was measured after the stack was irradiated with sound waves for 5 minutes. Next, the cooling end of the stack was heated using a heater, and the input power to the heater was measured when the temperature difference between the two ends of the stack was zero[8]. The results of these measurements were summarized for each stack length to confirm the trend of change.

Table I Parameters in each metal mesh.

Type	20 mesh	50 mesh
Wire diameter mm	0.18	0.10
Flow path diameter mm	1.09	0.408
Aperture rate %	74	65

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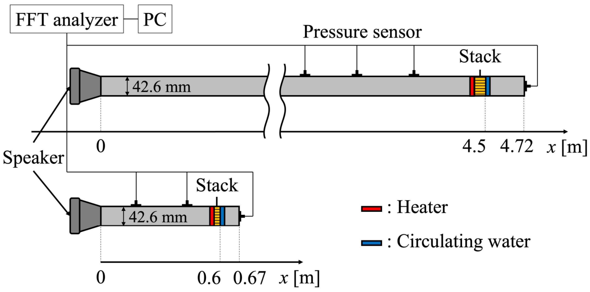

Fig. 1 Experimental setup.

4. Results and discussion

The results of the temperature difference at both ends of the stack versus stack length are shown in **Fig. 2**. The trend of change is consistent for both 20 and 50 mesh. The stack lengths at which the temperature difference between the two ends of the stack was maximum were 40 mm for the 20 mesh and 9 and 11 mm for the 50 mesh. On the other hand, the temperature difference at both ends of the stack tended to decrease for stack lengths longer than 40 mm for 20 mesh and for stack lengths longer than 11 mm for 50 mesh.

The results of heat input versus stack length are shown in **Fig. 3**. The trend of the heat input change for the 20 mesh was similar to that of **Fig. 2**. The other side, the 50 mesh showed a slower change compared to the result in **Fig. 2**.

The trends of the temperature difference at both ends of the stack and the heat input with respect to the stack length was focused on the number of metal mesh layers[9]. As the number of metal mesh layers increases, i.e., as the stack gets longer, the aperture ratio of the stack decreases. Therefore, we believe that the fraction of sound waves reflected by the stack increased in proportion to the length of the stack.

5. Conclusion

The study focused on the stack length under the condition that $\omega\tau$ is constant. From the experimental results at each mesh number, it can be said that the trends of the temperature difference at both ends of the stack and the heat input with respect to the stack length are consistent regardless of the total length of the system. Hence, similar trends in temperature difference at both ends of the stack and heat input as in the present experiment can be expected when a system with an overall length about 100 mm is studied in the same way.

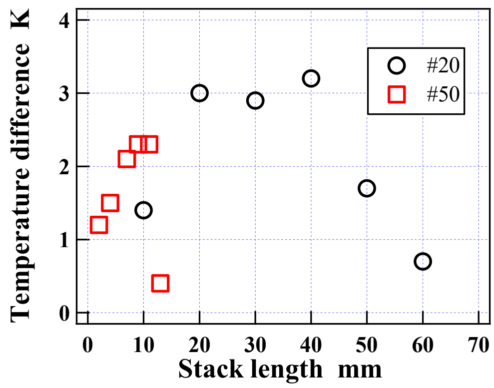

Fig. 2 Trend of temperature difference at both ends of stack with respect to stack length.

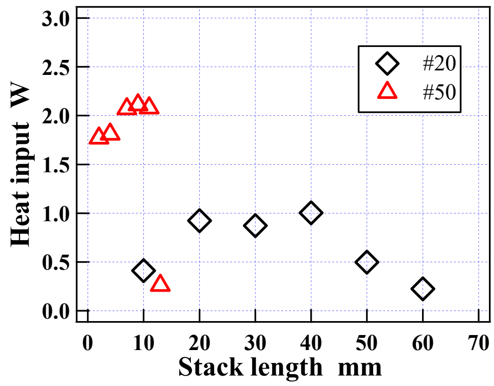

Fig. 3 Trend of heat input with respect to stack length.

Acknowledgment

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