3P4-9

# Study for low-temperature driving of a loop-tube-type thermoacoustic system
# -Relation between stack humidification and acoustic streaming -
# ループ管型熱音響システムの低温駆動に向けた検討
# -スタック加湿と音響流の関係-

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## 1. Introduction

A thermoacoustic system utilizing the thermoacoustic phenomenon[1)] that is the mutual energy conversion between heat and sound has a feature of being able to harness unused energies such as waste heat. Toward the effective use of this system, the lowering of the oscillation temperature is desired. As a manner for lowering the temperature, the humidification of the stack has been proposed[2)]. However, since the mechanism that the wet stack lowers the oscillation temperature of the system is scarcely known, the present authors are also studying on the function of the wet stack from various viewpoints. In such a process, the rapid temperature rise has been found at the hot end of the stack at the moment that the stack changes from the wet condition to the dry condition. Such a rapid temperature rise is hard to interpret as a phenomenon caused by usual heating. Thus, considering that this phenomenon is caused by the inflow of high-temperature fluid particle due to acoustic streaming, the influence of the acoustic streaming on the stack humidification is experimentally investigated in this report by inserting a thin film in the system to suppress the acoustic streaming.

## 2. Experiment

### 2.1 Experimental setup

The system used in the experiment is roughly illustrated in **Fig. 1**. Using a stainless tube with a 42 mm inner diameter, a loop tube of 200 mm in total length is constructed. A stack of honeycomb ceramics with a 50 mm thickness and a 0.45 mm flow-path radius is set at 350 mm from the bottom end of the system. By installing a electric heater and water circulator at its both ends, a prime mover (PM) is constituted. As a film to suppress the acoustic streaming, a 0.03 mm thick rubber is used. Further, to avoid the change of the sound field, the film is set at the position of 1100 mm from the high-temperature end of the stack where the node of the particle velocity locates.

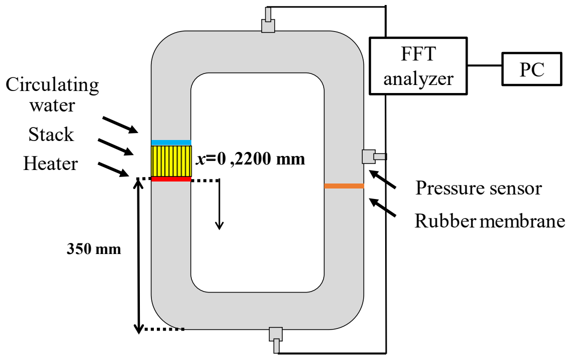


Fig. 1 Experimental system.

### 2.2 Experimental condition

The input power to the electric heater and the temperature of the circulating water are kept constant at 165 W and 20°C, respectively. Water of 30 g is then added. The sound pressure in the tube and the temperature $T_h$ at the hot-end of the stack are measured with a pressure sensor (product of PCB Co.) outside the tube wall and a K-type thermocouple, respectively. Under the above condition, the temperatures $T_h$ in the cases with and without the film are compared. In this report, the condition of low-temperature driving is called the wet condition. In addition, the condition where a high temperature seems to be attained after the stack is dried due to the thermal input is called the dry condition. The sound intensity $I$ [W/m$^2$] at each condition is evaluated by the following equation.

$$I = \frac{1}{2}|p||u|\cos\phi, \tag{1}$$

where $p$ is the sound pressure, $u$ is the particle velocity, and $\phi$ is the phase difference between the sound pressure and the particle velocity.

## 3. Results and Discussion

The resonance frequencies in the cases with and without the film are both 160 Hz where the total tube length becomes a wavelength. The sound intensity in the tube is shown in **Fig. 2**. From this figure, assuming that the acoustic intensity produced in the stack is the difference $\Delta I$ of the sound intensities at the hot-end and the cold-end of the stack, $\Delta I$ with the inserted film is 47 W/m$^2$ and that without the film is 13 W/m$^2$. It is found that the amount of energy production after insering the film is about three times larger comparing with the case without the film setting. These facts demonstrate the enhancement of energy conversion efficiency and suggest that the suppression of the acoustic streaming is useful for the effective driving of the system.

The temporal changes of $T_h$ in the cases without and with the film are shown in **Figs. 3** and **4**, respectively.

From these results, the following facts are found: (1) The oscillation temperature increases about 40°C by inserting the film. (2) Regardless of presence or absence of the film, the temperature decreases about 10°C with the lapse of time. (3) The oscillation time in the wet condition is extended about 60 s by inserting the film. (4) In the case with the film, the temperature does not increase rapidly at the transition from the wet condition to the dry condition.

Concerning (1), since the reflection ratio of the film measured at 160 Hz is 7.5%, the increase of the energy dissipation in the total system caused by the inserted film seems to result in the rise of oscillation temperature. In addition, since the fact described in (2) occurs due to the heat flow generated by the oscillation, it is found that the film insertion scarcely affects the heat flow in the stack. Furthermore, gathering the above results and (3), the usefulness of the film is confirmed in the case where the waste heat of mid temperature exceeding 140°C is used for the thermal input. That is, the suppression of the acoustic streaming by inserting the film induces the increased energy production in the stack and the extended low-temperature driving time, and then the efficiency of the whole system is assumed to be enhanced. The rapid temperature rise that is observed at the transition from the wet condition to the dry condition in the case without the film never occurs in the case with the film. It is confirmed that the temperature rise is caused by the local shift of heat due to the acoustic streaming.

## 4. Conclusion

Humidifying the stack of the thermoacoustic system, the difference in the temperature transition of $T_h$ between the cases with and without setting the film was observed. As a result, the rise of oscillation temperature and the increase of the acoustic intensity were found in the case where the film was inserted. On the other hand, the rapid increase of $T_h$ never occurred. From such results, it was suggested that the rapid temperature rise peculiar to the wet condition was the influence of the acoustic streaming and the efficiency of the whole system would be enhanced by setting the film in the case where mid-temperature waste heat is employed as the thermal input.

## Acknowledgment

This work was supported by JSPS Grant-in-Aid for Young Scientists A (22686090), JSPS Grant-in-Aid for Challenging Exploratory Research (23651072), Grant-in-Aid for Scientific Research C (40449509), Program for Fostering Regional Innovation and JST Super cluster program.

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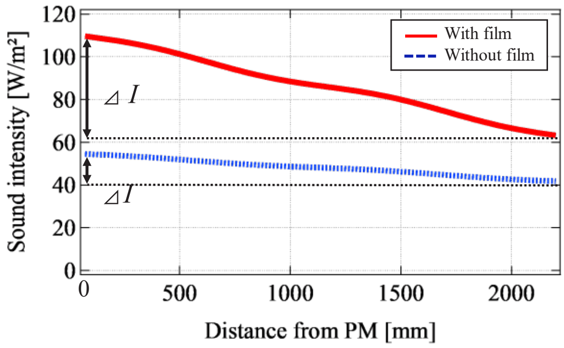


Fig. 2 Distributions of sound intensity.

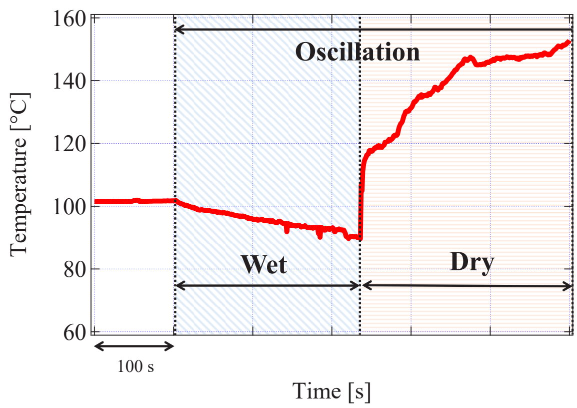


Fig. 3 Transition of $T_h$ in the case without film.

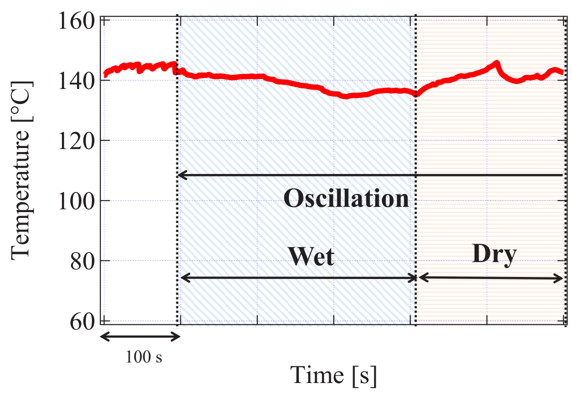


Fig. 4 Transition of $T_h$ in the case with film.