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Loop-tube-type thermoacoustic system saturated with water vapor -Observation of stability of low-temperature driving-
飽和水蒸気環境下におけるループ管型熱音響システム -低温度駆動の安定性の観察-

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1. Introduction

A thermoacoustic phenomenon[1)] is the interconversion between the heat energy and the sound energy. When the temperature gradient is produced by inserting a stack in a cylindrical tube, the energy conversion from heat to sound takes place. Since the thermoacoustic system is an external combustion engine, there is an advantage that unused energies such as waste heat may be utilized. However there is also a disadvantage that the oscillation temperature is too high to utilize the waste heat at low temperature range of 350-450K. Among the waste heats from factories and so on, the total amount of the lower-temperature waste heat at 350-450K is predominantly greater than that of the high-temperature waste heat at 550-1000K. To utilize this, the reduction of the driving temperature is desired.

As a method to lower the oscillation temperature, the use of water vapor as a working fluid has been proposed.[2-4)] The waste heat that is supplied is assumed to be mainly water vapor, and it is considered that easy to make effective use in this method. Although there are many studies by linear shape systems, there are few studies by a loop-tube-type system[5)], which has been reported to have high energy conversion efficiency.

In this report, water vapor was supplied to the loop-tube-type system to confirm the oscillation temperature and the durability of oscillation.

2. Experiment

2.1 Experimental setup

Experiments are carried out using the loop-tube-type system illustrated in **Fig. 1**. The loop consists of a stainless tube 48 mm in diameter and 2200 mm in length. At the bottom of the system, a 100 mm pipe with the same diameter was installed for storing water. A stack with the same diameter is set at 450 mm from the bottom end. A 50 mm long honeycomb ceramics with a 0.55 mm channel radius is employed for the stack. The high-temperature end of the stack is heated with an electric heater (PM heater) installed there.

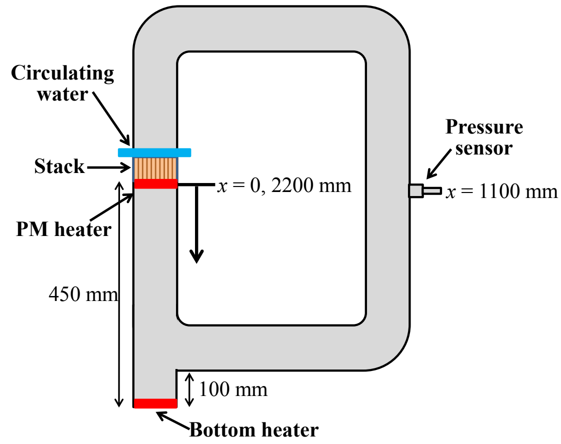

Fig. 1 Experimental system.

The water kept at room temperature is circulated around the tube of the low-temperature end of the stack. An electric heater (bottom heater) is installed at the bottom end for generating the water vapor. A pressure sensor (PCB Piezotronics) was installed at a position 1100 mm from the high temperature end of the PM, and the sound pressure inside the pipe was measured. The temperatures T_h and Tc at the stack ends as well as the T_b at the bottom end are measured with K-type thermocouples.

2.2 Experimental condition

Dry condition The air of atmospheric pressure is used as the working fluid in the dry condition. The relative humidity was about 50%. The high-temperature exchanger is heated and the low-temperature exchanger is cooled by circulating water.

Wet condition The water vapor is used as the working fluid in the wet condition. After pouring 30 ml of water in the bottom, the system is sealed. The electricity is then turned on to the bottom heater for the water. At this moment, the high- and low-temperature exchangers are not operated yet. When the bottom end temperature T_b increases over 363K and starts supplying the vapor, the high- and low-temperature exchangers are operated.

In both conditions, gradually increasing the input of the high-temperature exchanger, T_h and T_c at the start of the oscillation are measured. Assuming that the waste heat supposed to be a heat source continuously supplies a stable temperature, this report evaluates by the oscillation temperature.

3. Results and Consideration

Figure 2 shows the time transition of the sound pressure at the dry condition. In this report, when reaching 10% of the maximum amplitude of the waveform is defined as oscillation, T_h at the start of oscillation is defined as the oscillation temperature. It was confirmed that the oscillation temperature under each condition was 538, 377K in the dry and wet conditions, respectively, and the wet condition oscillated at a low temperature. Also, if the time from the start of oscillation to 90% of the maximum amplitude of the waveform is defined as the rise time, the time in the wet condition is shorter than the dry condition.

Figure 3 shows the time transitions of the T_c and T_h at the each condition. For each condition, the time at the start of oscillation is adjusted to the position of 100 seconds. In the dry condition, T_h and T_c do not fluctuate greatly after oscillation. However, in the wet condition, fluctuations in T_h and T_c are confirmed despite not changing the input to the PM heater after oscillation. Immediately after oscillation, T_h decreased sharply and T_c increased. T_h decreased to 361K, but the oscillation continued for about 300 seconds. After that T_h surged. Immediately temperature changes after the oscillation are thought to be due to heat flow. The water vapor in the stack evaporates by driving the PM heater. It is thought that T_h suddenly increased because the wet condition was damaged by heating. By keeping the stack in the wet condition, it is expected that the low-temperature driving will be continued.

In order to confirm the stability of the oscillation, the fluctuation of the resonance frequency on the frequency spectrum regarded. Small fluctuation of the resonance frequency means stable oscillation, and the magnitude of the fluctuation can be evaluated by the Q value. The Q value represents the sharpness of the spectrum of the resonance frequency. It is thought that the Q shows the high value when in the stable oscillation. Under each condition, when the Q value was calculated from the sound pressure spectrum at the start of oscillation, it was 74.0 in the dry condition and 85.6 in the wet condition. Since the wet condition shows a higher Q value, the wet condition is a stable oscillation environment than the dry condition. In order to maintain a stable oscillation environment, it is important to keep the stack in the wet condition.

4. Conclusion

A steam supply, which is a method of driving a thermoacoustic system at a low-temperature, was introduced into a loop-tube-type system. Although the oscillation temperature decreased as a result of the experiment, it did not continue to operate at low temperature. In order to sustain low-temperature driving, it is considered important to keep the stack in the wet condition.

Acknowledgment
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References
[1] P.H.Ceperley, J. Acoust. Soc. Am.,Vol.**66**,No.5, pp.1508-1513, 1979.
[2] R.Raspet *et al*., J.Acoust.Soc.Am, **112**(4), pp.1414-1422,2002.
[3] K. Yasui *et al*., J. Acoust. Soc. Am., **141**(6), pp.4398-4407, 2017.
[4] S. Kawaminami *et al.*, Jpn. J. Appl. Phys.,**56**, 07JE12, 2017.
[5] T. Yazaki *et al*., Phys. Rev. Lett., Vol.**81**, No.15, pp.3128-3131, 1998.

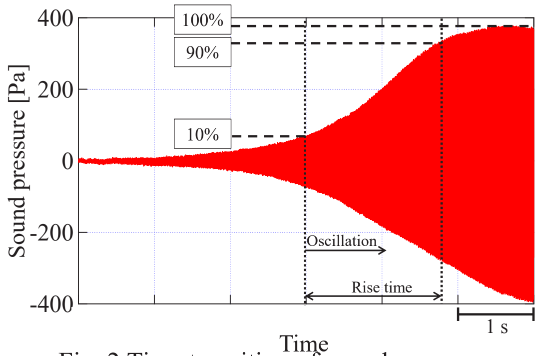

Fig. 2 Time transition of sound pressure at the dry condition.

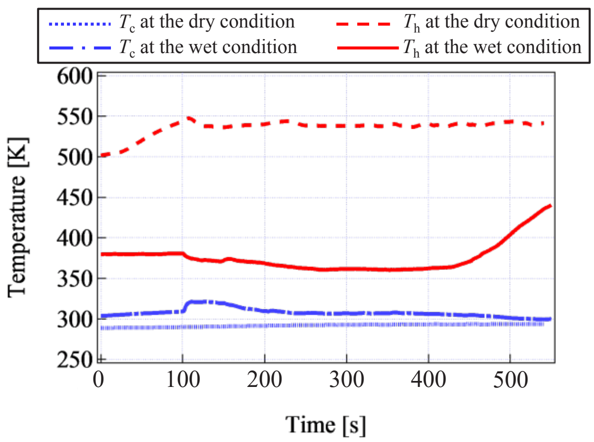

Fig. 3 Time transitions of T_c and T_h.