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Step-type thermoacoustic system using the phase transition -Study toward the low temperature excitation-

相変化を利用した段差型熱音響システム -低温度駆動に向けた検討-

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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 thermal acoustic 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 323-423 K. Among the waste heats from factories and so on, the total amount of the lower-temperature waste heat at 323-423 K is predominantly greater than that of the high-temperature waste heat at 573-1273 K. To utilize this, the reduction of the driving temperature is desired.

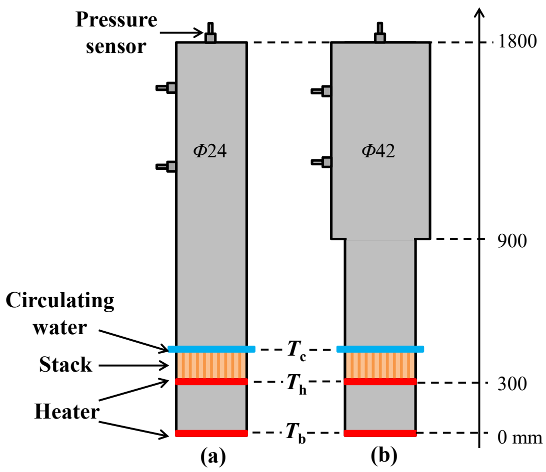
As a manner to lower the temperature, the use of a two-phase fluid (vapor and waste) has been proposed[2)]. It is possible to reduce the oscillation temperature to 340K by utilizing the phase change[3)]. Sound waves are easy to occur ,by pressure change due to the evaporation and condensation can cause expansion and contraction of the gas. The technique to lower the temperature by using a step-type system with a stepwise change in its inner diameter has also been presented[4)].

In this report, the possibility of further lowering of the oscillation temperature is examined by using the tow-phase fluid in a step-type system.

2. Experiment

2.1 Experimental setup

Experiments are carried out using the straight type and step-type systems illustrated in **Fig. 1**. The straight type system consists of a stainless tube 24 mm in diameter and 1800 mm in length. A stack with the same diameter is set at 300 mm from the bottom end. A 50 mm long honeycomb ceramics with a 0.55 mm channel radius is employed for the stack. Two heat exchangers work as a prime mover (PM). While the high-temperature exchanger is an electric heater wound in the tube, the low temperature exchanger is a water circulation around the tube. An electric heater is installed for generating steam at the bottom end. The step-type system is obtained by replacing the top half of the straight system with a tube 42 mm in inner diameter. According to the previous studies, the length ratio of the tubes of different inner diameters is set 1:1 so as to realize the oscillation at the lowest temperature. Other sizes are the same as the straight type. The sound pressure amplitude in the tube is measured with pressure sensors (product of PCB Piezotronics). Temperature at the stack ends (T_h and T_c) and bottom end (T_b) are measured with K-type thermocouples. Using the transfer matrix method[5)], the sound field in the tube is calculated from the measured pressure.



(a) Straight type. (b) Step-type.
Fig. 1 Experimental systems.

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 two-phase fluid is used as the working fluid in the wet condition. The

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stack is dipped in water to contain moisture well. Then, after taking out the water, the stack is shaken for removing the water. By measuring the weight of the stack, the adherence of a 7.5 g water is assumed. After setting the stack and pouring 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 373 K 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. The oscillation temperature ratio $OTR = T_h/T_c$ is derived from the measured values. The amounts of water poured into the bottom end are 10 g and 20 g that exceed the amount of the saturation vapor content for the straight-type and the step-type tubes, respectively to become the relative humidity nearly about 100%.

3. Results and Consideration

Table 1 shows T_h, T_c and *OTR* to start oscillation in each condition. The step-wet system oscillates at lower temperatures comparing the step-dry and straight-wet systems where a low temperature oscillation is expected. In each condition, the system is stably driven without stopping the sound at the temperatures shown in **Table 1**.

Figure 2 shows the distribution of the sound pressure at the start of oscillation. Comparing the step-dry system and the step-wet system, it can be seen that the sound pressure distributions are the same to each other throughout the tube. Therefore, when the wet condition is set, the oscillation temperature must be lowered while keeping the output level the same. The step-type system is compared with the straight-type system both at the wet condition next. In the portion of 350-900 mm with the same diameter, the distribution is almost the same. However the sound pressure is reduced to approximately 1/3 at the portion whose cross-sectional area is enlarged. To withdraw the energy from a thermoacoustic system, a heat pump (HP) stack can be installed in the system. When the HP stack is set within the range of 900-1800 mm, the stack diameter is affected by the ratio of the cross-sectional areas. In this experiment, the ratio of the straight-type to the step-type is 1:3. This means that the number of the channel in the HP stack for the step-type system would be larger by 3 times. Provided the energy output is proportional to the channel number, the output of the same level as the straight-type system can be expected even by the step-type system at the wet condition. Summarizing the above discussion, the step-type system working at the wet condition, where the lowest oscillation temperature and the output of the same level are expected, is considered to be available for the oscillation at low temperatures.

Despite the straight-wet system of this report oscillated at 438K, the system of previous study[3] had oscillated at 340K. The step-wet system can be expected further reduction temperature oscillation, if it is possible to oscillate at about 340K combined conditions such experimental systems.

4. Conclusion

Toward the excitation at lower temperature, the step-type thermoacoustic system was experimentally examined using a two-phase fluid. Compared to the step-dry system and the straight-wet system where the low temperature oscillation is expected, the step-wet system oscillated at lower temperatures. Despite the oscillation temperatures are different, the sound pressure during the oscillation showed similar distributions. Because of the stable oscillation at low temperatures, the step-type thermoacoustic system using a two-phase fluid was suggested to be available for the low-temperature driving.

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Table. 1 Measured temperature at the start of oscillation.

	T_h[K]	T_c[K]	*OTR*
Straight-Dry	614	290	2.1
Step-Dry	518	289	1.8
Straight-Wet	438	290	1.5
Step-Wet	364	290	1.3

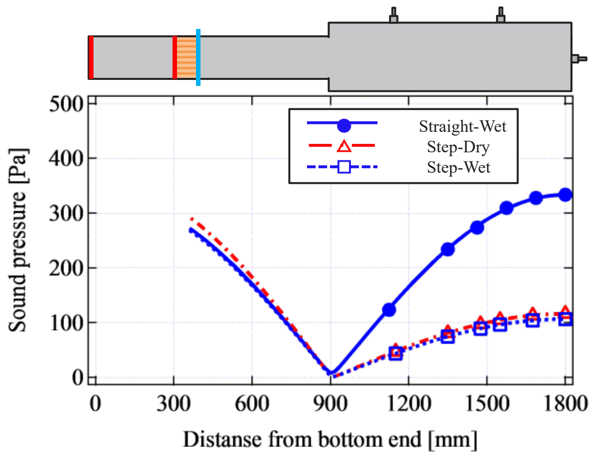

Fig. 2 Distribution of sound pressure at the start of oscillation.