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Fundamental study of a loop-tube-type thermoacoustic heater
ループ管方式熱音響ヒーターの基礎研究

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1. Introduction

We propose a thermoacoustic heating system based on the thermoacoustic effect. In a thermoacoustic heating system, the supplied sound energy is converted to heat energy and the heating point is heated. A thermoacoustic heating system differs from a thermoacoustic cooling system: the location of the reference temperature section at the heat pump is upside down. The sound energy is supplied to the heat pump; then the heating point reaches 100°C. It must be emphasized that, using this simple and inexpensive thermoacoustic heating system, noise is useful as a renewable energy source.

Considering the limitations of natural energy resources, introduction of renewable energy is encouraged. Herein, we propose a thermoacoustic heating system based on the thermoacoustic effect[1–3]. Many reports have described thermoacoustic cooling systems[2–6], but none have presented a thermoacoustic heating system. The principle of a thermoacoustic heating system is the same as that of a thermoacoustic cooling system; in a thermoacoustic heating system, the supplied sound energy, such as noise, is converted to heat energy by the thermoacoustic effect. That energy heats the heating point.

2. Thermoacoustic heating system

A thermoacoustic heating system differs from a thermoacoustic cooling system: the location of the reference temperature section at the heat pump is upside down.

Figure 1 depicts a schematic diagram of the experimental setup of our loop-tube-type thermoacoustic heating system. The loop tube consists of stainless steel tubes connected by 90-deg elbow tubes. The total tube length is 3.3 m. The tube diameter is 42 mm. A prime mover and a heat pump are placed symmetrically in the loop tube.

For this experiment, the sound energy to be supplied to the heat pump is first generated in the loop tube by the thermoacoustic effect at the prime mover. The electric power is supplied to the prime mover to generate the sound in the loop tube. The prime mover consists of a 0.45-mm-channel-radius stack and heat exchangers A and B. For heat exchanger A, a whorl-shaped electric heater is used. Electric power of 330 W is supplied to the electric heater. Heat exchangers B are maintained at the reference temperature. These heat exchangers create a temperature gradient in the prime mover stack, thereby generating sound.

The sound generated at the prime mover propagates in the loop tube and is subsequently supplied to the heat pump. The heat pump consists of a 0.35-mm-channel-radius stack and heat exchangers B and C. Heat exchanger C is the heating point. Heat exchangers B and C also create a temperature gradient in the heat pump stack. This temperature gradient causes energy conversion from sound energy to heat energy, which heats the heating point.

In a thermoacoustic cooling system, the cooling point is the lower temperature part and the reference temperature section is the higher temperature part. In contrast, in a thermoacoustic heating system, the heating point is the higher temperature part and the reference temperature section is the lower temperature part. The difference between the roles of the higher and lower temperature sections is the crucial difference of a thermoacoustic heating system and thermoacoustic cooling system.

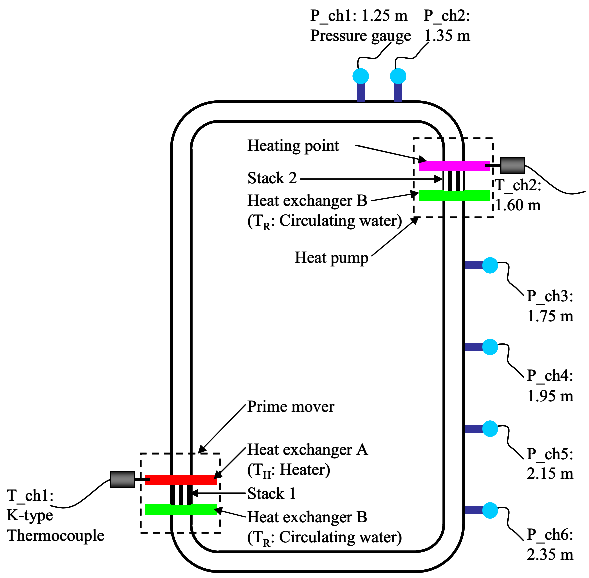

Fig. 1 A thermoacoustic heating system

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3. Experiment

As the working fluid filled in the loop tube, a mixture gas of helium and argon (50: 50) is used at atmospheric pressure. The temperatures at the upper end of the prime mover stack and at the heating point are measured using K-type thermocouples. The sound pressure of the sound generated in the loop tube is measured using six pressure gauges: P_ch1 – P_ch6. They are placed, respectively, 1.25, 1.35, 1.75, 1.95, 2.15, and 2.35 m distant from the upper end of the prime mover stack in a clockwise arrangement. The particle velocity, the acoustic intensity and the phase difference between the sound pressure and the particle velocity are calculated using the two-sensor power method[6, 7], based on the observed sound pressures obtained using the pressure gauges. The electric power supply and the measurements of the temperatures and the pressure are started simultaneously. The measurements are continued for 600 s.

Figure 2 shows the temperature variation at the heating point. The sound is generated about 12 s after the electric power supply. The temperature at the heating point starts to increase after the sound is generated, and reaches 100°C.

Figure 3 presents the spatial distribution of the sound pressure in a steady state 400 s after the electric power supply. Figures 3 portray that the sound generated in the loop tube is resonated with the total tube length at one-wavelength resonance, and that the antinode of the sound pressure and the node of the particle velocity are around the heat pump.

Results obtained in this experiment demonstrate that, using this simple and inexpensive thermoacoustic heating system, noise can serve as a renewable energy resource.

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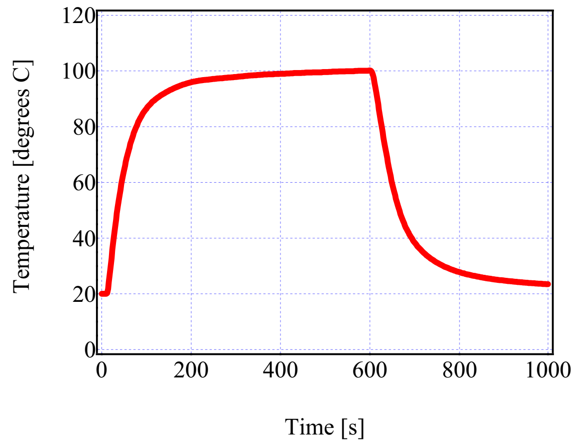

Fig. 2 the temperature variation at the heating point

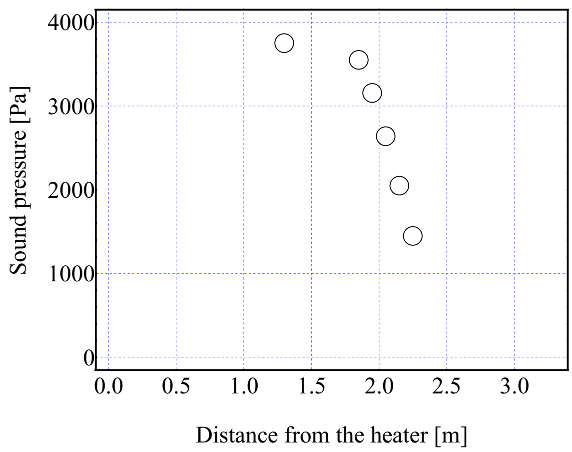

Fig. 3 the spatial distribution of the sound pressure in a steady state 400 s after the electric power supply