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Fundamental study for the solution of thermoacoustic phenomenon using numerical calculation – Relation between the setting position of stack and heat flow –

数値計算による熱音響現象の解明に向けた基礎研究 - スタック設置位置と熱流の関係 -

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1. Introduction

Sound waves that propagate in a sufficiently narrow tube compared to their wavelength produce heat exchange on the wall. This phenomenon known as thermoacoustic phenomenon [1], and thermoacoustic systems using the thermoacoustic phenomenon have entered practical use in many fields. A porous device called a stack is often used in the thermoacoustic systems to achieve energy conversion of heat and sound. These systems are useful especially when driven by unused energy sources such as waste heat and solar heat because they are external combustion engines. They have the possibility as a global environment maintenance technology. Nevertheless, their energy conversion efficiency is lower than that of internal combustion engines and examples of their practical use are few. To improve the energy conversion efficiency, methods of system design such as form and installation position of the stack have been investigated experimentally [2]. Assessment of design methods through experimentation requires much time and cost because it is necessary to structure the systems one by one. Moreover, the low degradative ability is problematic. Therefore, a system design method using mathematical calculations was examined [3].

The heat flow in the stack was calculated by producing an arbitrary system, and then using calculations for its analysis. As a result, Q_D that decrease the performance of the system was dominant in each heat flow element [1]. The value of Q_D reduced by installation the stack near the node of particle velocity. Therefore, this report describes influence given to Q_D and ΔI that contributes to energy conversion efficiency when the stack installation position is changed.

2. Principle

2.1 Calculation method

Formula (1) show Rott's wave equation matrix, which is used for math calculations [3].

$$\frac{d}{dx}\begin{bmatrix} P \\ U \end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{i\omega\rho_m}{1-\chi_\nu} \\ -\dfrac{i\omega}{\gamma P_m}\left\{1+(\gamma-1)\chi_\alpha\right\} & \dfrac{(\chi_\alpha-\chi_\nu)}{(1-\mathrm{Pr})(1-\chi_\nu)T_m}\dfrac{dT_m}{dx} \end{bmatrix}\begin{bmatrix} P \\ U \end{bmatrix} \tag{1}$$

Therein, P and U respectively denote the sound pressure and the particle velocity, and ω, ρ_m, γ, P_m, Pr, and T_m respectively represent the angular frequency, the mean density, the ratio of specific heat, the mean pressure, the Prandtl number of the working gas, and the mean temperature. Also, χ_α and χ_ν are complex function that relates thermal diffusion and viscosity, respectively. It is defined by Formula (2).

$$\chi_{\alpha,\nu} = \frac{2J_0\left((i-1)\sqrt{\omega\tau_{\alpha,\nu}}\right)}{(i-1)\sqrt{\omega\tau_{\alpha,\nu}}\,J_1\left((i-1)\sqrt{\omega\tau_{\alpha,\nu}}\right)} \tag{2}$$

In that equation, J_1 and J_0 are the first- and zeroth-order Bessel function, and τ_α and τ_ν are the thermal and viscosity relaxation time, respectively.

The boundary condition of the system used for this study accommodated the Dirichlet type because the system is a closed tube. In calculations, the resonance frequency and the temperature ratio at both ends of the stack are chosen to satisfy boundary conditions, and the sound distribution in the tube is decided. In this report, these how to request it are omitted.

2.2 Heat flow

Heat flow by the fluid oscillation is the following [1].

$$Q = Q_{prog} + Q_{stand} + Q_D \tag{3}$$

Therein, Q_{prog} and Q_{stand} are the heat flow element by a progressive wave and a standing wave, and Q_D is the heat flow element by the dream pipe effect. In the thermoacoustic phenomenon, Q_{prog} and Q_{stand} contribute to energy conversion well, but Q_D does not contribute to it much. Therefore, it is considering that the energy conversion efficiency improves by reducing Q_D. In addition, setting up the stack near the node of particle velocity reduces Q_D

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because it has a dependency on particle velocity.

3. Experimental system and methods

A diagram of the measurement system is presented in Fig. 1. This experiment used a straight tube with both ends closed. The system was 2000 mm total length and 24 mm inner diameter. The stack was a 50 mm-long honeycomb ceramic with a channel having a 0.45 mm radius. Circulating water and an electric heater were set up at both ends of the stack, and a temperature gradient was formed at both ends of the stack. Electric power of 200 W is supplied to an electric heater. Furthermore, a K-type thermocouple is applied to measure both ends of the stack. Firstly, the installation position of a stack was 700 mm. Secondly, The installation position of a stack was changed to 800 mm and 900 mm for reference from 700 mm. We defined the left end position as 0 mm. The stack installation position is defined as the position of circulating water. Pressure sensors (PCB Inc.) were set on the system wall to measure the sound pressure in the tube. The sound intensity, the sound pressure, and the heat flow ware calculated using pressure measurement results.

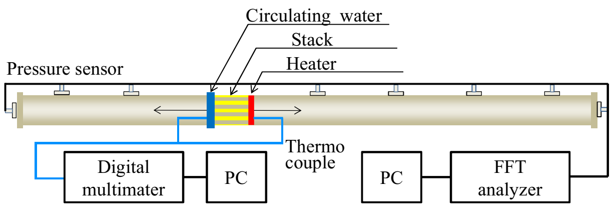

Fig. 1 Diagram of measurement system.

4. Results and discussion

Figure 2 presents calculating results of each heat flow element in the stack when the stack is set at the 700 mm position. Regarding heat flow in the stack, Q_D was confirmed as superior from Fig. 2. It is necessary to decrease Q_D for making the system highly effective

Figure 3 presents the distribution of Q_D in the stack when the stack installation position is changed. Results show a decreasing tendency of Q_D with installation of the stack at the center of the tube. The node of particle velocity is put in the center part of the tube because the sound waves, of which one wavelength is the total length, are formed. Therefore, the placement reduced Q_D by setting up the stack near the center part of the tube. The distribution of the sound intensity in the tube calculated by using result of an experiment is portrayed in Fig. 4. Energy conversion improves by amount ΔI of amplification of the sound intensity in the stack. The values of ΔI when the installation position of the stack is 700, 800, and 900 mm are, respectively, 63, 280, and 490. Therefore, we infer that Q_D can be reduced by setting up the stack near the center part of the tube.

5. Conclusions

The heat flow in the stack was calculated. Results confirmed that Q_D was dominant. An experiment setting up the stack near the node of particle velocity to reduce Q_D showed a decrease of Q_D. Furthermore, the energy conversion efficiency was improved.

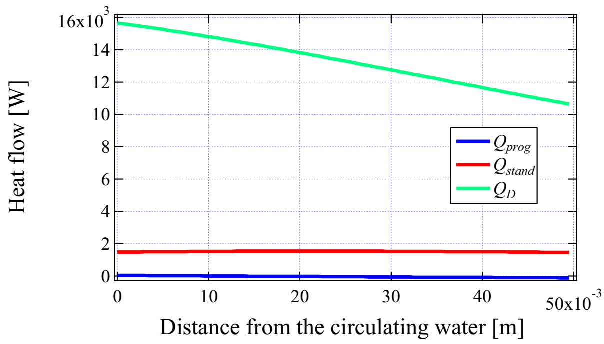

Fig. 2 Each heat flow element in the stack when the stack's position is 700mm.

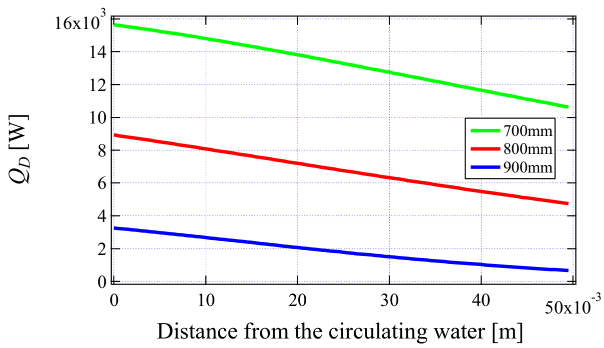

Fig. 3 Q_D distribution in the stack when the stack's position is changed.

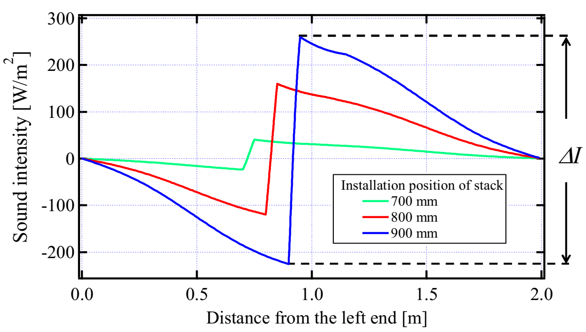

Fig. 4 Distribution of sound intensity in the tube.

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