Energy conversion efficiency improvement of a thermoacoustic cooling system -The influence of a lamination mesh on cooling effect-

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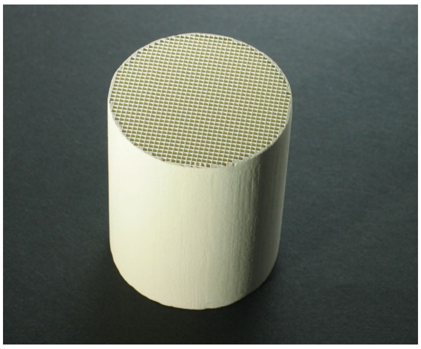
Experimental investigations have been carried out to improve the thermoacoustic cooling performance of the loop tube cooling system. It was generally considered that energy conversion efficiency of a thermoacoustic cooling system was improved by increasing proportion of a thermal boundary layer in a stack. Thinning down a channel radius of the stack is required to increase the thermal boundary layer per unit area. It is difficult for a ceramic stack to satisfy this requirement. We use a lamination mesh which is formed by piled up a stainless mesh to satisfy this requirement. Since the lamination mesh has complex channels, the effect of changing the mesh number on the cooling effect is obscure. The experiments were carried out by changing the mesh number and the insertion position of the stack using the straight acoustic tube to measure the cooling effect. From an experimental results, the insertion position of the lamination mesh for which the maximum temperature decrease comes close to a center of the acoustic tube. This is corresponded to a result using the ceramic stack. It suggests that a same design method, which is applied the ceramic stack, can be adapted to a case of using the lamination mesh.

1 Introduction

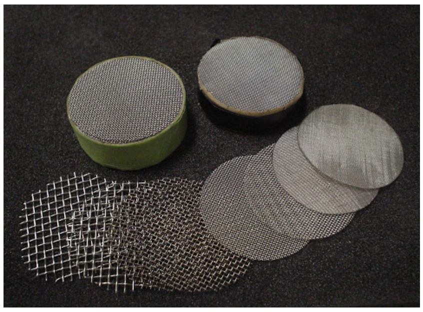
Recently, efforts to conserve the global environment have been exerted worldwide. Ozone depletion by chlorofluorocarbon refrigerants and global warming by greenhouse-effect gases such as carbon dioxide have been recognized as causes of global environmental destruction. The development of new energy sources and technologies to preserve the global environment are urgently required. Focusing on thermoacoustic phenomena [1], where the conversion between heat energy and sound energy takes place, the present authors are pursuing the establishment of a basic technology that can contribute toward global environmental conservation.

By applying the thermoacoustic phenomena, it is possible to construct a green cooling system [2-7]. A thermoacoustic cooling system does not employ harmful refrigerants such as chlorofluorocarbons. Further, this system can utilize waste heat as an energy source. In addition to such advantages, the system works without any moving parts. Hence the realization of this system is very attractive.

A loop tube is one of the thermoacoustic cooling system. The loop tube consists of a prime mover and a heat pump. At the prime mover, heat energy is converted to sound energy, and at the heat pump, sound energy is converted to heat energy by applying the thermoacoustic effect. A stack having very narrow channels, as shown in Fig. 1(a), is in the prime mover and the heat pump. We have been studying about the energy conversion in the stack of heat pump using acoustic tube connected compression driver, for example a loudspeaker etc. Recent studies have suggested that the best insertion position of the stack is decided by uniquely when varying the drive frequency and channel radius of the stack under identical $\omega\tau$ [3, 8], which is non-dimensional parameter. Altogether, the best insertion position of the stack becomes clear if we could estimate $\omega\tau$ of stack.



(a) Ceramic stuck.



(b) Stainless mesh.

Fig.1 Photograph of various stacks.

Meanwhile it was generally considered that energy conversion efficiency of a thermoacoustic cooling system was improved by increasing proportion of a thermal boundary layer in the stack. The thermal boundary layer affects the level of the heat exchange between the oscillating gas and stack channel walls. Thinning down a channel radius of the stack is required to increase the thermal boundary layer per unit area. It is difficult for a ceramic stack to satisfy this requirement. We use a lamination mesh which is formed by piled up a stainless mesh to satisfy this requirement. The lamination mesh is shown in Fig. 1(b). Since the lamination mesh has complex channels, the value of $\omega\tau$ applying lamination mesh is obscure. For this reason, it is difficult to estimate the best insertion position. In this paper, the best insertion position of the lamination mesh is investigated. In addition, the value of $\omega\tau$ applying lamination mesh is estimated based on the experimental results and relationship between the value of $\omega\tau$ applying ceramic stack and the best insertion position of the ceramic stack**.**

2 Theory

When ordinary sound propagates through free space, the period of compression and expansion of the sound wave is very short. The medium through which the sound propagates undergoes an adiabatic change because of the absence of objects through which heat dissipates. On the other hand, when the sound propagates through narrow channels such as a stack and the period of compression and expansion of the sound wave is very long, the medium close to the stack channel wall undergoes an isothermal change and the medium exchanges heat with the channel wall. This heat exchange induces mutual energy conversion between sound energy and heat energy, and this mutual energy conversion is the thermoacoustic effect.

Heat exchange efficiency between a working gas and the stack channel wall surface varies from a ratio between period of the oscillating gas and a thermal relaxation τ, which is the time required for thermal equilibrium in the cross section of the flow channel and expressed using the following equation (1).

$$\tau = \frac{r^2}{2\alpha} \qquad (1)$$

Where r is the channel radius of the stack and α is the thermal diffusivity.

$$\alpha = \frac{\kappa}{c_p \rho_m} \qquad (2)$$

Where κ, c_p, and ρ_m are thermal conductivity, heat capacity per unit mass, and mean density. Therefore, the non-dimensional parameter $\omega\tau$, which is standardized by period of the oscillating gas, is generally used as a controlling the energy conversion parameter. Where ω is an angular frequency of the sound wave. When the working gas and temperature is constant, $\omega\tau$ depends on only the resonant frequency and the channel radius of the stack. If $\omega\tau << 1$, the working gas in the stack moves isothermal, whereas if $\omega\tau >> 1$, the working gas motion becomes adiabatic. However $\omega\tau \sim 1$ due to incomplete heat transfer to the stack channel wall, which is effective for the thermoacoustic cooling system.

3 Experimental Methods

The block diagram of measurement system is illustrated in Fig. 2. A loudspeaker is put into one side of the acoustic tube and the other side is a closed end. The inner diameter of the acoustic tube is 0.042 m. The driving frequency is set as 100 Hz to generate one-wavelength mode. Three lamination meshes are formed by piled up a stainless mesh at 15 mm. Each mesh number, which is number of mesh per inch, is 10, 20 and 40. The system is filled with air at the atmosphere pressure. The loudspeaker side of acoustic tube is defined as a forward, and the closed end side is defined as a backward. The backward of the lamination mesh is defined as an insertion position of the lamination mesh. We gradually moved the insertion position from 1.60 m to 1.85 m, and measured temperature change on the backward of the lamination mesh. This temperature change is measured using K-type thermocouple.

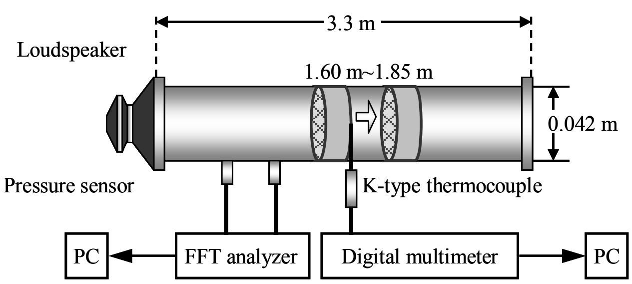


Fig.2 Block diagram of measurement system.

4 Results

Several temperature decreases were measured at the measurement point when changing the insertion position and lamination mesh. The temperature decreases at the measurement point are shown in Fig. 3. It is assumed that the peak position of the temperature decrease is the efficient position for the heat exchange. To estimate each peak position of temperature decrease, three-dimensional approximated curve was calculated and is showed Fig. 4. The peak positions of 10, 20, and 40 mesh were observed in 1.74, 1.70 and 1.66 m.

5 Discussion

To simplify these results, the peak positions were normalized by length of the acoustic tube. As it turns out,

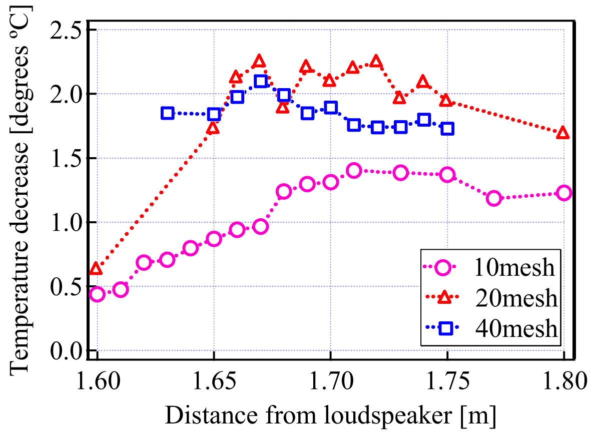


Fig.3 Temperature decrease as a function of the stack position distance from the loudspeaker.

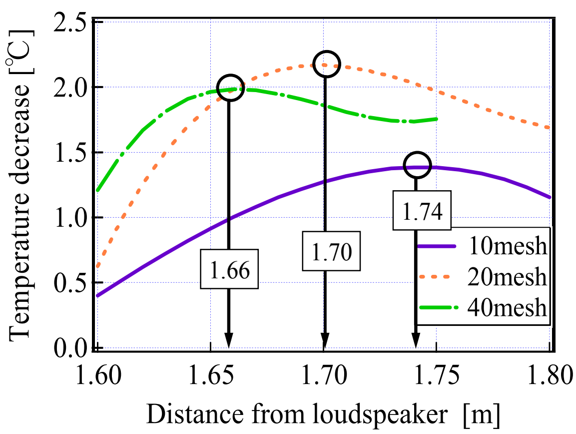


Fig.4 Temperature decrease fitted curve as a function of stack position distance from loud speaker.

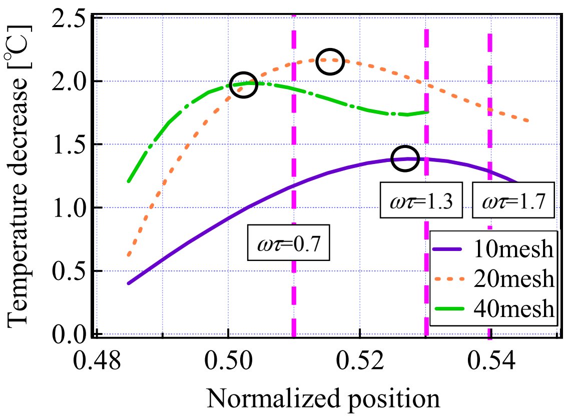


Fig.5 Temperature decrease fitted curve as a function of normalized position for comparison between ceramic stack and lamination mesh.

the normalized peak positions of 10, 20, and 40 mesh were 0.527, 0.515 and 0.503. Therefore peak positions come close to center of the acoustic tube due to increase mesh number. The previous research [8] has revealed that changing the value of $\omega\tau$ applying ceramic stack induce shifting the peak position. For this reason, changing the mesh number of the lamination mesh evoke varying the value of $\omega\tau$ applying lamination mesh. Results of past research about the normalized peak position under each value of $\omega\tau$ applying ceramic stack and experimental results are shown in Fig 5. The results show that $\omega\tau$ of 10, 20 mesh were approximately 1.3, 1.0, and $\omega\tau$ of 40 mesh smaller than 1.0.

6 Conclusion

To measure the cooling effect of lamination mesh, the experiments were carried out by changing the mesh number and the insertion position of the lamination mesh using the straight acoustic tube. The experimental results demonstrated that the peak positions of temperature decrease come close to center of the acoustic tube because of increasing mesh number. The previous research using ceramic stack suggests that the peak position of temperature decrease varies by $\omega\tau$. Thus increasing mesh number of lamination mesh involves varying $\omega\tau$. Moreover, the value of $\omega\tau$ applying lamination mesh was estimated by utilizing the previous research. It suggests that a same design method, which is applied the ceramic stack, can be adapted to a case of using the lamination mesh.

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