# Alteration Of Thermo Acoustic Heat Pumping Direction Through Magnitude Difference Variation Of Opposing Acoustic Waves

A. Widyaparaga[1,a], T. Hiromatsu[2], T. Koshimizu[3], M. Kohno[2] and Y. Takata[2]

[1]Department of Mechanical Engineering, Gadjah Mada University, Jl. Grafika 2, Yogyakarta, Indonesia 55281
[2]Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Japan 819-0395
[3]Kitakyushu National College of Technology, 5-20-1 Shii, Kokuraminami-ku, Kitakyushu, Japan 802-0985
Correspondence email :

**Abstract:** Thermo acoustic refrigeration utilizes the temperature changes which occur due to pressure oscillations within a sound wave to transport heat from one point to another and achieve cooling. As such, it does not require complicated machinery nor hazardous or environmentally harmful refrigerants. In addition, the direction and intensity of heat pumping can be altered by modifying the direction and intensity of the acoustic power flow, thus allowing a single device to be capable of functioning as a heater or cooler without addition of complicated machinary. One method of altering the acoustic field is by varying the magnitude of two opposing travelling waves. For this purpose, we have constructed a thermo acoustic heat pump employing dual opposing acoustic drivers connected by a resonator tube and a regenerator formed by layers of steel mesh positioned at the center of the resonator. Experiments were conducted using a frequency of 260 Hz. The acoustic field was manipulated by changing the magnitude of one acoustic driver while keeping the other driver constant.
**Keywords :** Thermo acoustics, travelling wave, magnitude difference

## 1. Introduction

Thermo acoustic refrigeration is a promising alternative method of temperature control to vapor compression methods which utilizes temperature changes caused by pressure oscillations present within sound waves to transport heat from one point to another, therefore does not require hazardous or environmentally harmful substances. A typical thermo acoustic device consists of at least these three main components: a resonator tube, a source of acoustic power, and a regenerator. The regenerator is the heart of the function of the thermo acoustic device. This regenerator may consist of a stack of parallel plates or porous media which function is to receive and transfer heat to the oscillating air "packets" of the sound wave. It is expected that heat is transported from one side of the regenerator ("cold side") to the other side ("hot side"). By positioning heat exchangers on both sides, heat can be removed from the "hot side" and the "cold side" can receive heat from an outside chamber or material, thus allowing the device to function as a cooler or refrigerator.

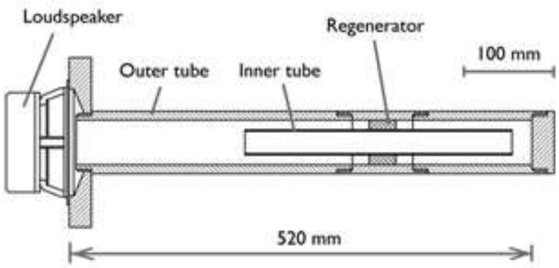


**Figure 1.** Coaxial Thermo acoustic device

[1]Corresponding author: E-mail: adhikayev@gmail.com

The distance between the plates or the porosity of the media in the regenerator will depend on the type of thermo acoustic device. For a standing wave thermo acoustic device, good contact but less than perfect thermal contact between the gas and regenerator surfaces are required, while for a traveling wave thermo acoustic device, perfect thermal contact is required. Thus, pore sizes or distances between plates is smaller for travelling wave devices than for standing wave devices.

In a previous study, we designed and experimented on a travelling wave thermo acoustic refrigerator employing a coaxial design. A diagram of the device is shown in FIgure 1. Through trials conducted at several operating frequencies, it was discovered that the resulting temperature distribution differed for each frequency. For several frequencies, it was observed that the minimum temperature of the regenerator was not at one side but within the regenerator. The “hot side” and the “cold side” of the regenerator were also found to reverse.

Travelling wave thermo acoustic theory states that the direction of heat pumping within the regenerator is opposite to that of the direction of acoustic power flow. Thus, the change of frequency altered the acoustic power flow direction which ultimately changed heat pumping direction. As the acoustic field and acoustic power flow are determined by the superposition of travelling waves propagating in opposite directions along the resonator tube, to better understand the phenomena, the effect of changes in the individual opposing waves must be investigated.

The acoustic power intensity within the regenerator can be determined for a monofrequency acoustic wave:

$$I = \frac{1}{8\omega\rho}\left\{\mathrm{Im}[H](|p_+|^2 - |p_-|^2) + 2\,\mathrm{Re}[H]|p_+||p_-|\sin\theta\right\} \tag{1}$$

using

$$H = \frac{kF}{\cos(\tilde{k}dx)\sin(kdx)} \tag{2}$$

where $|p_+|$ and $|p_-|$are the magnitudes of the positive direction travelling wave and the negative direction travelling wave respectively.$\rho$ is the mean density of the gas, Re[ ] and Im[ ] represent the real and imaginary components. $\theta$=arg[$p_+/p_-$] represents the phase lead of $p_+$ relative to $p_-$. Also, $k$ represents the complex wave number and $F$ is a complex factor. By modified two-sensor method, the values of $k$ and $F$ are:

$$F = 1 - \frac{2J_1(i^{3/2}\sqrt{2}r_0/\delta)}{i^{3/2}(\sqrt{2}r_0/\delta)J_0(i^{3/2}\sqrt{2}r_0/\delta)} \tag{3}$$

and

$$k = -ik_0\sqrt{\frac{J_0\left(i^{3/2}\sqrt{2}r_0/\delta\right)}{J_2\left(i^{3/2}\sqrt{2}r_0/\delta\right)}}\sqrt{\gamma + (\gamma-1)\frac{J_2\left(i^{3/2}\sqrt{2\sigma}r_0/\delta\right)}{J_0\left(i^{3/2}\sqrt{2\sigma}r_0/\delta\right)}} \tag{4}$$

where $J_n$ is the $n$th order complex Bessel function, and $\sigma$ and $\gamma$ denote the Prandtl number and the specific heat ratio.

Based on equation 1, it can clearly be seen that the acoustic field can be altered by varying the phase and magnitudes of the opposing waves. To this end, we constructed a thermo acoustic device consisting of two opposite facing acoustic drivers connected by a resonator tube. The two opposing acoustic drivers thus enabled the manipulation of positive and negative direction travelling waves within a single frequency as opposed to the frequency dependent reflections experienced in the previous coaxial device. In this paper, we will report the effect of changes in acoustic power magnitude between the opposing acoustic drivers towards determining the heat pumping within the regenerator.

## 2. Experimental Apparatus and Methods

We constructed a thermo acoustic device consisting of two opposite facing speakers. Two Jordan JX-92S full range woofers were used as the two opposite facing acoustic drivers. Thus, alteration of phase and magnitude of the two speakers independently was possible thus enabling manipulation of positive and negative direction travelling waves. A picture of the dual speaker device is shown in Figure 2.
The input signals were generated using two Agilent 33220A waveform generators connected to a Yamaha P-1000S Amplifier. The waveform generators were time synchronized to allow consistent phasing between the two. An operating frequency of 260 Hz was used.

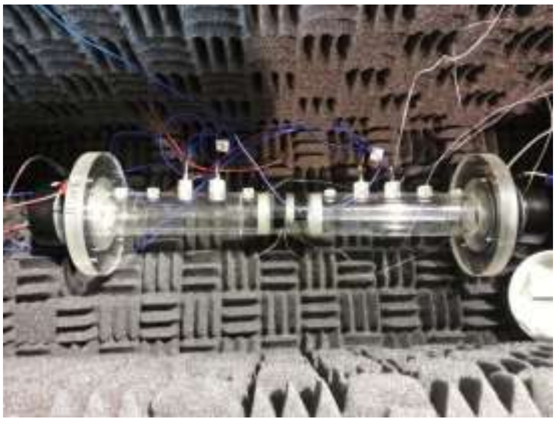

Figure 2. Dual Speaker Thermo acoustic Device

An acrylic tube with an inner diameter of 50mm and wall thickness of 5mm was used as the resonator. The working flow was air at atmospheric pressure and temperature.
The regenerator was constructed of 230 sheets of stainless steel mesh with a mesh number of 150. The mesh sheets were stacked to a total regenerator length of 30mm. The mesh openings had a hydraulic radius of 0.025mm which is smaller than the thermal penetration depth for 250Hz.
Temperature measurements were conducted using five Type K thermocouples positioned within and at the ends of the regenerator which were connected to an Agilent 34970A data acquisition unit. The thermocouples at the regenerator ends were designated as T1 located at the end of the regenerator facing speaker B and T2 located at the end facing speaker A. Three additional thermocouples were positioned within the regenerator as such so that the five thermocouple positions were at regular intervals along the regenerator.
We experimented in changing the input power of one acoustic driver (Speaker A) from zero to 3.8 W, while the other acoustic driver (Speaker B) was kept at 23 W. Phase difference between Speaker A and Speaker B is kept at zero degrees. Input power measurement was conducted using a Hioki 3334 powermeter. The temperatures at the regenerator were recorded for a running time 60 minutes.

## 3. Results and Discussion

Figure 3 and Figure 4 show the temperature change within the regenerator ($T_A$, $T_B$, $T_C$) and at the ends of the regenerator ($T_1$, $T_2$) during a 60 minute running for Speaker A input power of 0 W and 5.7 W respectively. As stated above, the input power for Speaker B was kept at 23 W.

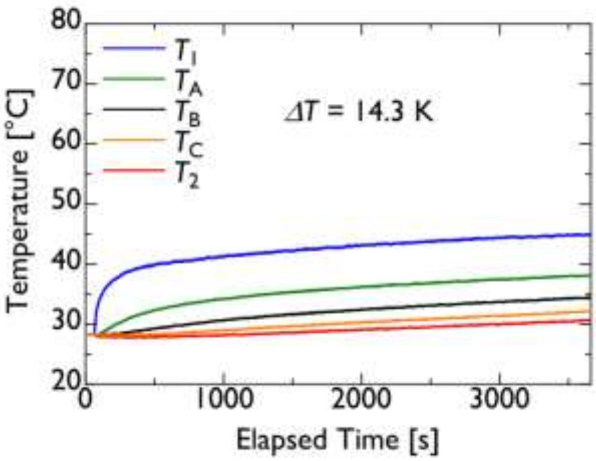


**Figure 3.** Temperature development for 0 W Speaker A Input Power

As can be seen, the change of power at Speaker A has resulted in a change of temperature distribution development within the regenerator. The temperature distribution at the $T_1$ end of the regenerator (the end facing Speaker B) was found to be similar between 0 W and 5.7 W.
The temperature development for $T_A$ was slightly different, being 1 degree lower in temperature after 60 minutes. The further away from $T_1$, the differences in temperature development are more pronounced between 0 W and 5.7 W.

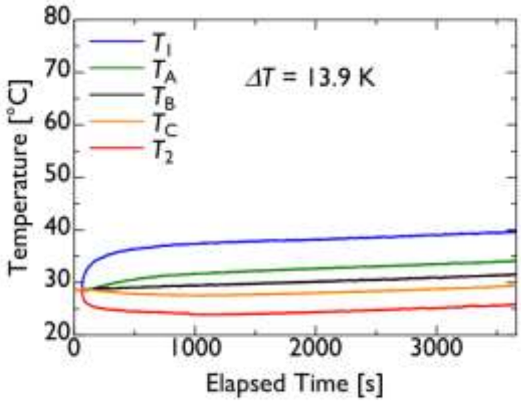


**Figure 3.** Temperature development for 5.7 W Speaker A Input Power

At the $T_2$ end, the temperature was not found to significantly reduce for 0 W, while for 5.7 W, a temperature reduction was observed.

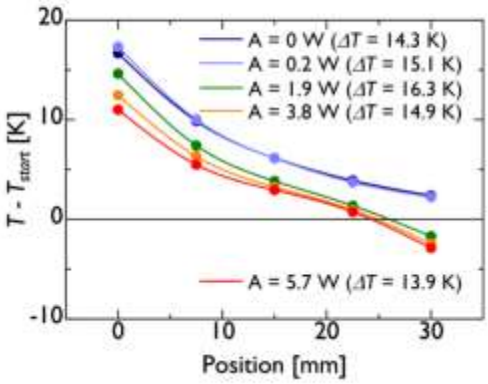


**Figure 4.** Temperature distribution within the regenerator
for Speaker A input powers 0 W to 5.7 W

ISBN 978 979 8510 61 8

Figure 4 shows the final temperature distribution along the regenerator for Speaker A input powers 0 W to 5.7 W. As expected temperature distribution varies for changes in Speaker A input power. Interestingly, the temperature difference between both ends of the regenerator increased from 14.3 K to a maximum of 16.3 K as power was increased from 0 W to 1.9 W, after which increasing power further resulted in a decrease in temperature difference.We can thus see that heat pumping is improved by Speaker A. As according to equation 1, it can be deduced that up to 1.9 W Speaker A input power, the wave interactions between travelling waves from Speaker A and B were as such as to increase acoustic power leaving the $T_2$ side of the regenerator.

## 4. Conclusion and future work

We have constructed a dual acoustic driver thermo acoustic travelling wave heat pump for the purpose of evaluating the effect of opposite direction propagating travel wave interaction on acoustic field development and heat pumping. In this experiment we have kept one acoustic driver (Speaker B) at 23 W and have varied the input power for the other acoustic driver (Speaker A) from 0 W to 5.7 W. The results have revealed that from 0 W up to 1.9 W Speaker A input power, the heat pumping was improved, indicated by an increase of temperature difference from 14.3 K to 16.3 K between the ends of the regenerator. Increasing input power above 1.9 W, however, gradually reduced performance.

To fully investigate the changes in acoustic field due to the change in input power to Speaker A, a pressure wave decomposition and calculation of acoustic power intensity will be conducted based on pressure measurement data within the regenerator. Calculating acoustic power will provide more information regarding the direction of the acoustic power flow and the interactions of the opposing waves.

## 5. Nomenclature

| | |
|---|---|
| $J_n$ | *n*th order complex Bessel function |
| $p$ | pressure |
| $r_0$ | radius |
| $r_{h,regen}$ | hydraulic radius |
| Re[ ] , Im[ ] | real and imaginary components |
| $t$ | time |
| $x$ | displacement |
| $\delta$ | viscous boundary layer thickness |
| $k_o$ | wave number in free space |

## 6. References

Biwa, T., Y. Tashiro, H. Nomura, Y. Ueda, and T. Yazaki. "Acoustic Intensity Measurement in a Narrow Duct by a Two-Sensor Method." *Review of scientific instruments* 78, no. 8 086110-10-3. (2007)

Fusco, A.M., W.C. Ward, and G.W. Swift. "Two - Sensor Power Measurements in Lossy Ducts." *The Journal of the Acoustical Society of America* 91 2229. (1992)

Swift, GW. *Thermo acoustics: A Unifying Perspective for Some Engines and Refrigerators Acoustical Society of America*. Sewickley, PA: Acoustical

Society of America, 2002.
Tominaga, A. *Fundamental Thermo acoustics*. Tokyo: Uchida Rokakuho, 1998.
Widyaparaga, A., T. Koshimizu, E. Noda, N. Sakoda, M. Kohno, and Y. Takata. "The Frequency Dependent Regenerator Cold Section and Hot Section Positional Reversal in a Coaxial Type Thermo acoustic Stirling Heat Pump." *Cryogenics* 51, no. 10. (2011)

**Acknowledgements**

We would like to thank AUN/SEED-NET and JICA for providing the SRJP fellowship for this research.