Experimental investigation on the effect of resonator shapes on the temperature characteristic of thermoacoustic cooling device

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Abstract. Thermoacoustic refrigerator has emerged as one of new alternative ways of cooling. The use of this technology which converts sound energy to heat energy has not been popular despite its environmentally friendly and simple construction. A laboratory scale thermoacoustic cooling device has been constructed to conduct experiments on three different shapes of resonators that results in temperature difference occurring at its stack ends. Geometry of the device parts is one of the parameter that holds importance to its characteristic. The device applied a different shape of resonator for each experiment and record temperature data at stacks ends. The experiments were conducted with variations in resonator which are square tube, cylinder tube and tapered tube. The material of resonator is acrylic and its inner volume remains unchanged.

1. Introduction

The need for reliable and sustainable refrigeration technology is ongoing demand of today’s world where one of daily living necessities is non-stop availability of cooling energy. The efforts to maintain supply of this energy conventionally relies on fossil fuel power which generate electricity. Even though this large need for refrigeration and freezing technology on different temperature levels has been served by vapour compression cycles and absorption cycles, thermoacoustic refrigeration has a potential as alternative cooling provider [1]. The use of massive conventional refrigeration technology development has a negative impact on the environment due to heavy air pollution that causes undesired impacts to the environment which is known as global warming. Refrigerant such as chlorofluorocarbons gas (CFCs) or hydrofluoric carbons (HFC)s are dangerous for the earth, because it can damage the ozone layer that results in the increase of temperature on earth.

Due to its tropical climate, and uncertain climate change, the existence of cooling systems is needed in Indonesia. Conventional cooling systems generally use Freon and CFC or HFC refrigerants as their working medium. The use of such substances has the potential to cause long-term hazards such as global warming. Therefore, an environmentally friendly non-CFC / HFC alternative cooling system such as thermo-acoustic cooling system is required. Specifically, thermoacoustic are sound waves that can cause temperature differences at the two ends of the stack because of the air through small channels in varying shapes, materials, stack designs and resonators [2].

Thermoacoustic devices have attracted the attention and interest of researchers in recent years because they are environmentally friendly, durable, and relatively have simple parts that can be installed and operated at a relatively low cost. On the other hand, thermo-acoustic refrigerators use a medium of working air or noble gases as an alternative to conventional cooling systems so as to be harmless to the environment [3]. In addition to its many advantages, the thermoacoustic refrigerator has its disadvantages, that it is generally very low in efficiency.

The effects of stack parameters and frequency variation on the thermal performance of thermoacoustic refrigerator by using acrylic resonator tubes of 4.0 cm and 5.3 cm diameter with stack thickness variation of 0.15mm, 0.5 cm and 1 mm has been investigated [4]. Based on some research
that has been done by previous researchers, a continuous development is required by varying the geometry of the resonator tube and the stack form an important first step for the performance of thermo-acoustic cooling devices. The main problem in this research is how the effect of resonance frequency changes on the geometry variation of resonator tube, and the stack shape on thermo-acoustic performance.

Thermoacoustic is the event of heat transfer by sound waves or vice versa [5]. Thermoacoustic itself is a combination of two fields of science, which are acoustics and thermodynamics. Simple construction that typically produces thermoacoustic effects is commonly referred to as thermoacoustic devices. Figure 1 shows some of the major parts of thermoacoustic device as shown in Fig. 1.

![Figure 1. Main components of Thermoacoustic device](image)

When working on the design of a thermoacoustic device, there are several things that must be considered, such as the dimensions of the resonator and of the stack. The frequency of input sound must be determined in order to be able to match the resonance frequency of a resonator tube.

While in designing the stack, the main limitation that is the width of the stack channel must be several times greater than the depth of the medium gas thermal penetration where the value of four in the ruler is the optimum distance value [6]. The thermal penetration depth ($\delta_K$) is the distance of heat diffusion through the working fluid or gas in this case being at a time interval $t = 1 / \pi f$, calculated by the equation:

$$\delta_K = \frac{K}{\pi \rho f c_p}$$

The basic concept of a thermoacoustic system utilizes sound waves generated by loudspeakers moving through a resonator tube that contains stack which act like a compressor in a vapor compression refrigeration. Air as a working fluid enters small canals located on the stack and compresses so that its temperature rises and releases heat to the material stack. The fluid further expands and decreases the temperature resulting in heat transfer resulting in temperature differences at the two ends of the stack. The transfer of heat from the air to the stack and vice versa is the result of acoustic waves that resonate in a tube that acts as an external work [7].

2. Research Methodology
The research was conducted at Thermal Engineering Laboratory of Faculty of Engineering, Syiah Kuala University and Thesis, Vibration and Acoustics Applied (PUSTVAT) University of Syiah Kuala Laboratory.

2.1. Material and Experimental set up
The material used for the resonator is acrylic, while the material for the stack is mica film. In this study first of all the calculated resonance frequency to be used in the research. To achieve this resonance frequency required a sound level meter measuring instrument placed at the end resonator. Sound waves generated from the function generator go through the amplifier and oscilloscope as a
wave reader, then from the amplifier to the loudspeaker. From this loudspeaker is the release of sound in the form of a frequency that has been set on the function generator to the level of the sound level meter and then from the sound level meter. Frequency used ranging from 40 Hz to 200 Hz with filter 1/3 octave. Figure 4 shows the resonance frequency data capture. From the test results obtained resonance frequency value of resonance-based resonator made of cylinder tube is 140 Hz, and resonator of tapered tube have resonance frequency of 160 Hz, as well as square tube resonator form resonance of 180 Hz. The shape and length of the resonator affect the resonance frequency, although the volume of the resonator shape is unchanged.

![Figure 2. Experimental set up of the thermoacoustic device](image)

Figure 2. Experimental set up of the thermoacoustic device

Figure 2 shows the experimental setup of the thermoacoustic device. The stack was placed at 6 cm from the closed end. The frequency and wave amplitudes were measured by a condenser microphone which was located at pressure anti node of the resonator. The microphone was connected to an oscilloscope. The oscilloscope confirmed the form and frequency of the wave input. Type K thermocouples were inserted at the ends of the stack and the temperatures were recorded every 30 second with Phywe™ measurement system.

3. Results and Discussion

Figure 3 shows the temperature data at the ends of stacks inside the square tube resonator, named Th and Tc. Th is the temperatures at hot side of the stack while Tc is the temperatures at cold side of the stack. After 30 seconds, the temperature of $T_h$ increased as much of $1.4 \ ^\circ\text{C}$ while $T_c$ decreased by $0.4 \ ^\circ\text{C}$. $T_h$ experienced an increase in temperature up to $32.2 ^\circ\text{C}$ at 540 seconds and a decrease of $26.1 ^\circ\text{C}$ at 630 seconds. Above 630 seconds there is no increase and decrease in temperature. The ambient temperature was $29 ^\circ\text{C}$.
Figure 3. Graph of temperature of square tube resonator

Figure 4 shows the temperature data at the ends of stacks inside the tapered tube resonator. After 30 seconds, the temperature of $T_h$ increased as much as 1.5 $\degree$C while $T_c$ decreased by 0.8 $\degree$C. $T_h$ experienced an increase in temperature up to 31.8$\degree$C at 540 seconds and a decrease of 25$\degree$C at 630 seconds. Above 630 seconds there is no increase and decrease in temperature. The ambient temperature was 29$\degree$C.

Figure 4. Graph of temperature of tapered tube resonator

Figure 5 shows the temperature data at the ends of stacks inside the cylinder tube resonator. After 30 seconds, the temperature of $T_h$ increased as much as 1.5 $\degree$C while $T_c$ decreased by 0.8 $\degree$C. $T_h$ experienced an increase in temperature up to 32.2$\degree$C at 540 seconds and a decrease to 24.8$\degree$C at 630 seconds. Above 630 seconds there is no increase and decrease in temperature. The ambient temperature was 29$\degree$C.
Figure 6 is calculations of temperature difference that occurred at both ends of the stack, for three variations of resonator shape. It shows the comparison of $\Delta T$ for each resonator. It indicates that the difference in temperature at the ends of the stack of the cylinder tube resonator is larger than other resonator shapes.

4. Conclusion

Experiments have been conducted to observe the temperature difference that occurred at the ends of the stack of a thermoacoustic cooling device. Each of three different shapes of acrylic resonator which have the same volume is tested at constant ambient temperature and same experimental set up. The input resonance frequency for each of resonator is different because the resonance frequency is the
function of resonator’s length and shape. The results showed that the cylindrical resonator has the largest temperature difference of 7.5°C, followed by truncated conical resonator with the temperature difference of 7°C. The cubical resonator produced the smallest temperature difference of 6.1°C. However, it is arguable that the resonator shape alone will have significant impact on temperature difference at stack ends of thermoacoustic cooling device.

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