Angles of Tilted and Length of Resonator Effect on The Efficiency of A Close-Open-Type Thermoacoustic

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Abstract

In determining the optimal design of the thermoacoustic engine, parameters were studied: tilt angle and resonator length. The purpose of this study is to find the highest efficiency in tilt angle and resonator length for a standing wave thermoacoustic engine (SWTE). The heat transfer properties therein were detected at three tilt angles of -90°, 0° and 90°, resulting in three resonator lengths variations such as 390, 780 and 1170 mm. This study was conducted to determine the magnitude of pressure amplitude using a two-pressure transducer method of recording by data acquisition and counting with Matlab software. The results of this study show that a tilt angle of 90° has the highest efficiency and a tilt angle of 0° has the lowest efficiency. A cavity length of 390mm yielded the highest SWTE efficiency, with an efficiency of 5.5%.

Keywords: efficiency; resonator length; swte; tilted angles

1. Introduction

Several years ago, attempts were made to compete with internal combustion engines for the acoustic performance of thermoacoustic engines in converting thermal energy into another energy. One example is converted to electrical energy. There are four types of sound-to-electricity conversion: equipment of electromagnetic, piezoelectric appliances, magnetohydrodynamic means, and bidirectional turbines [1]. In this work, one type of piezoelectric device, namely a thermoacoustic piezoelectric system named the Rijke-Zhao system, was applied to the study to describe the energy conversion process and thermal energy extraction by type [2]. Ere thermal energy is converted to electrical energy, and thermal energy is first converted to sound waves and then to electrical energy. In order for a thermoacoustic engine to generate sound waves, a waste heat source containing many heat sources is required.

One of the parameters affecting the sound power of a standing-wave thermoacoustic engine (SWTE) is the tilt angle of the tool. That is, by changing the positioning on the SWTE device at different angles which is tilt angles such as horizontal position called 0°, tilt position -45° and 45°, vertical position -90° and 90°. Some studies have been conducted with varying tilt angles from -90 to 90, resulting in several parametric analyses, comparing all working fluids except air [3]. The same study has since been performed [4], the study only accounted for one parameter, the onset temperature. The onset temperature is affected by the slope angle of the onset temperature and is also the decay behavior of the onset temperature. In this way, at the position of the inclination angle (−90°) where is the direction of temperature gradient with respect to the way of gravity, a possible natural-type convection can be promoted more. Therefore, the unfolding temperature of the SWTE was maximized when the device was at this tilt angle (-90°). In addition, there is a study [5] that did the same study using variations on different targets and another study [6] that also used the same variations such as tilt angle [6].

Cavity length is one of the other parameters that affects SWTE. Studies have shown that the shorter the resonator length, the higher the frequency (Hz) and sound power (W) [7]. As another study found the same result for frequency [8], the shorter the cavity length, the higher the frequency. Experiments and simulations were performed using delta EC with the working fluid in this study and with the resonator fully closed. The working fluids used in this study were nitrogen, argon and helium, which he on the other side varied to determine the best performance of the dual core on the SWTE side. The pressure inside this closed cavity was 5 bar. The higher the working fluid pressure, the better the performance of the thermoacoustic engine.

No studies have been published that efficiently present and analyze the relationship between tilt angle and cavity length with normal air as the working medium. These efficiency research goals are likely to be greater, as the performance of SWTE can be interpreted as being in good shape. Therefore, different tilt angles are used in this study. There are three tilt angles: (-90°), (0°), and (90°). Then there are also three resonators used as variations. Therefore, you should do some research with the variables of the above variants. The objective of this study is to study the effects of tilt angle and cavity length on the opening and closing efficiency of a thermoacoustic engine using only 1 atm air and room temperature between 25 °C and 27 °C. Experimental results were used to determine the effective position based on tilt angle and cavity length to achieve the best accomplishment or to explain the scholastic reasons why this phenomena occurred in SWTE, so essential.

2. Research Method

1.1. The Structures of Standing-Wave Thermoacoustic Engine (SWTE)

The structure of SWTE consists of several components. Figure 1. below illustrates the structures of SWTE. The components are noted in the information below the figure.

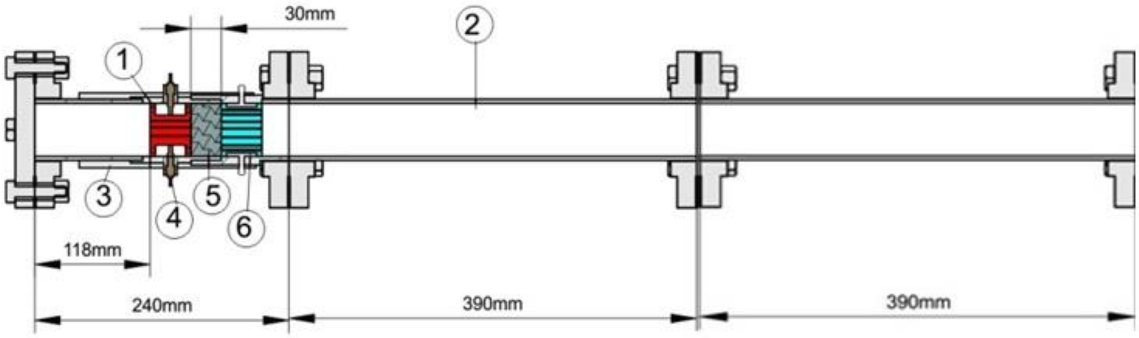

Figure 1. The SWTE's Components and Structures

the name of components:

1. Hot Heat Exchanger (HHX)
2. Resonator
3. Thermal insulation
4. Glow plug
5. Wire mesh
6. Cold Heat Exchanger (CHX)

1.2. Experimental Set Up SWTE with The Variation of Tilted Angles

In order to vary the tilt angle and obtain SWTE performance results, the experimental research setup can be modified at different tilt angles. During the experiment, the thermoacoustic engine was placed on the floor while the device was supported by an iron cantilever, except for horizontal positionings. Each experiment of the thermoacoustic engine was performed for each tilt angle. The angle is defined as a positive value when HHX is above CHX (90° tilt angle) and a negative shape when HHX is below HHX (-90° tilt angle), as shown in Figure 2. was defined as [9].

(a) (b)

Figure 2. The vertical positioning of tilted angles of thermoacoustic engine
(a) -90° and (b) 90° [9]

Inspections were performed every 90° from -90° to 90°. The 0° positioning is shown in Figure 3 [9]. The cavity length is defined as 780 mm. Therefore, a total of three tilt angles were tested, including (-90°), 0°, and 90°. A thermoacoustic engine consists of two heat exchangers (hot and cold heat exchangers), a thermoacoustic core, and tuned tubes. A thermoacoustic core between two heat exchangers was a key component of a thermoacoustic engine called a stack.

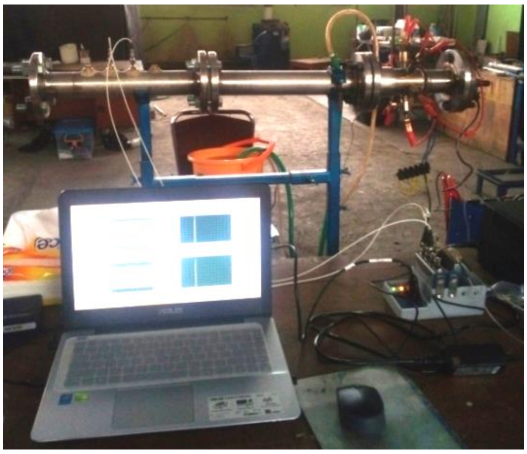

Figure 3. The horizontal positioning of tilted angle on 0° [9]

1.3. Experimental Set Up SWTE with The Variation of Tilted Angles

The cavity length in this study was divided into three sizes, which were 390, 780 and 1170 mm [10]. The resonator of Figure 4.

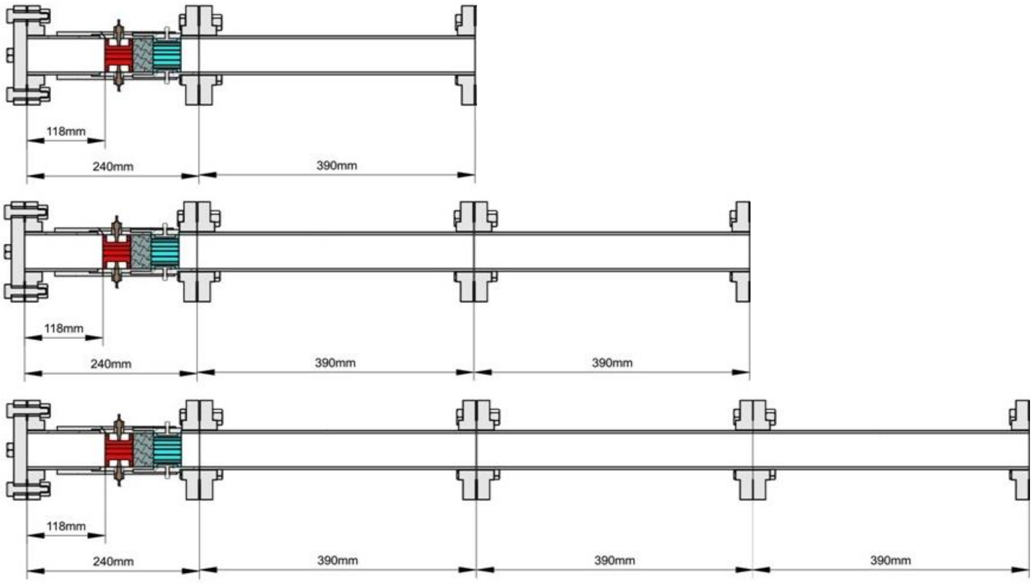

Figure 4. Three variations of resonator length of SWTE [10]

The actual experimental representations of three variations in cavity length are shown in Figure 5 for 390 mm, Figure 6 for 780 mm, and Figure 7 for 1170 mm.

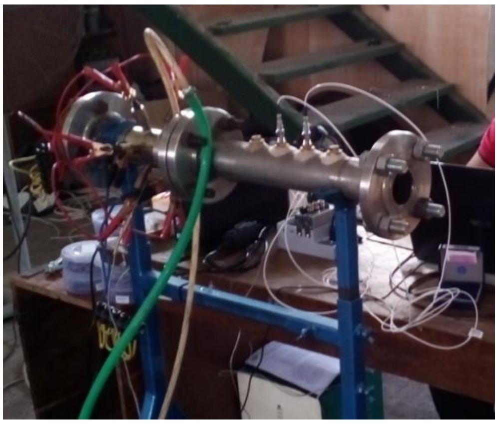

Figure 5. The resonator length with 390 mm long

Figure 6. The Resonator length with 780 mm long

Figure 7. The resonator length with 1170 mm long

2.4 Method to Calculate the Efficiency

First, obtaining the acoustic intensity (*I*) with the equation from previous author's journal [9] and [10]. Then we can enter it to the equation next to get the efficiency. A thermoacoustic engine requires a heat source ($\dot{Q}_h$) from an electric heater at a relatively high temperature (T_c) applies acoustic power ($\dot{E}$) , and dissipates heat ($\dot{Q}_c$) to the resonator, cooling water, and surroundings to do low temperature (T_H). Based on the laws of thermodynamics we can:

$$\dot{Q}_h = \dot{Q}_c + \dot{E} \tag{1}$$

The thermal-efficiency SWTE counts by using conduction and convection coefficients, these are both k and h, and it is given by this following:

$$\eta_{th} = \frac{\dot{E}}{\dot{Q}_h} \tag{2}$$

$$\eta_{th} = 1 - \frac{\dot{Q}_c}{\dot{Q}_h} = 1 - \frac{\dot{Q}_{resonator} + \dot{Q}_{cooling\ water} + \dot{Q}_{surroundings}}{\dot{Q}_h} \tag{3}$$

$$\eta_{th} = 1 - \frac{\left(kA\frac{\Delta T}{\Delta r}\right)_{resonator} + \left(mc_p\Delta T\right)_{cooling\ water} + \{hA_s(T_s - T_\infty)\}_{surroundings}}{\dot{Q}_h} \tag{4}$$

Finally, formulation allows for maximum efficiency:

$$\eta_c = 1 - \frac{T_c}{T_H} \tag{5}$$

The above efficiency calculations were performed and supported by Matlab to get the final data easier and faster.

3. Result and Discussion

In this part, the results of this study were discussed, starting with the effect of tilt angle and then cavity length. For the tilt angle, we have previously started elaborating the acoustic performance from other studies and then discussed the efficiency under the mentioned tilt angle variation. A discussion of the effect on cavity length variation then continued to a discussion of the efficiency of cavity length variation.

4.1 Acoustic Power

Figure 8 shows the data obtained by plotting the acoustic power obtained from the previous study [9] at various tilt angles. Learn how different tilt angles affect sound power. Researchers have found that the optimal position for this device is a 90° tilt angle. The sound power at a tilt angle of 90° was measured to be 10.7 Watts. At 0°, 0.5 watts was detected. Additionally, at -90° he recorded 6.7 Watts. This is shown in Figure 8. This can be inferred from the position of the thermoacoustic engine with the core positioned below the resonator (-90°). Acoustic power data are best due to natural convection taking place in the thermoacoustic's core. The experimental investigations were conducted at different tilt angles ranging from −90° to 90°. As the tilt angle decreases, the heat transfer coefficient between the working medium (gas fluid) and natural convection increases [9]. These tilt angles therefore have the effect of using less energy than other positions. Only suitable for use with thermal energy sources. Nevertheless, this declaration does not address sound power.

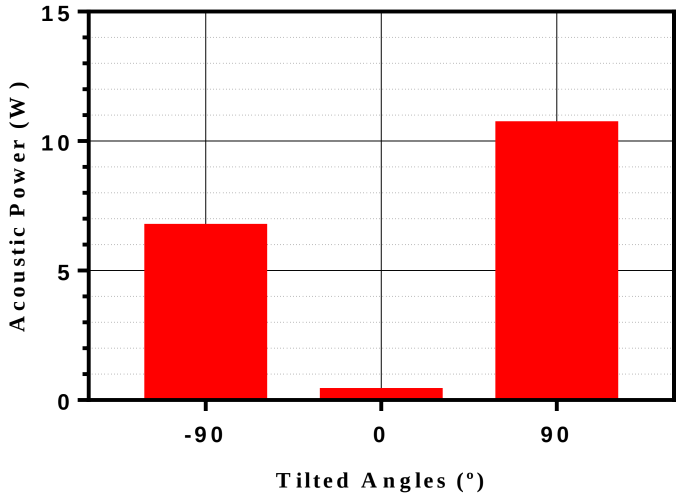

Figure 8. Effect of Tilted Angles toward Acoustic Power [9]

Apart from the atop explanation, it is precisely the phase of the wave that affects the performance results. Also called the phase difference, because of the difference in phase between the two waves measured at PT1 and PT2, respectively, it becomes a purpose of the acoustic power calculation [9].

The sound power trend is shown in Figure 9. It can be concluded that the shorter the resonator length, the greater the acoustic power. The related issue is also true for studies happened by these researchers, both [7] and [8].

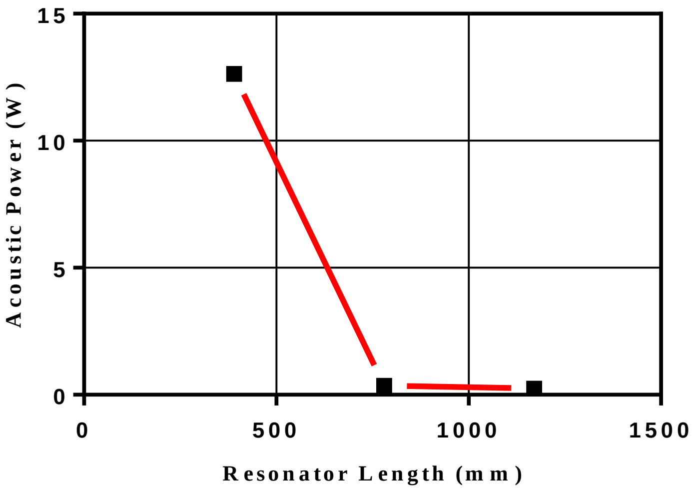

Figure 9. Effect of Resonator Length toward Acoustic Power

4.2 Efficiency

Figure 10 shows results of efficiencies with tilt angle change. Efficiency was obtained to be highest at a tilt angle of 90° with a value of 4.6%. The minimum value was 0° tilt angle with a value of 0.2%. For a tilt angle of -90°, the average value was between 0° and 90° with a value of 2.9%. This is because the efficiency is affected by the acoustic power, and the phase difference data at the tilt angle of 0° is the minimum value, so the acoustic power was obtained as shown in the above figure. We need to analyze this and get the answer why the phase difference shows a minimum at 0°.

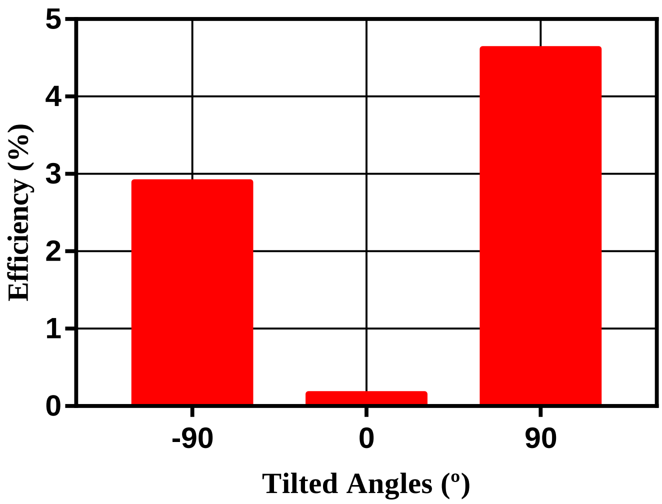

Figure 10. The Effect of Tilted Angles toward Efficiency

The highest efficiency based on cavity length variation was obtained with a value of 5.5% for the shortest cavity of 390 mm length. A trend can be drawn for the shortest cavity length and highest efficiency, as shown in Figure 11 below. It has more powerfull efficiency than both of two variations other. This can happen because on resonator length 390 mm has bigger value of frequency significantly, so that if it was put into the formula in equation in previous author's journal [9], that ω is the angular frequency linear to common frequency, then cause the value of acoustic power so that efficiency too in this variation of maximum resonator length resulted.

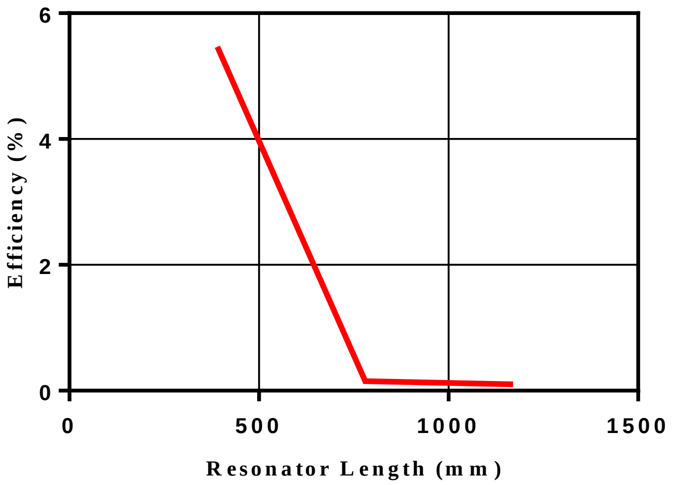

Figure 11. The Effect of Resonator Length toward Efficiency

A Sankey diagram below (Figure12), elaborated distribution of conversion of energy and loss of energy of SWTE. It seen the energy, thermal energy input, that is only a little percent obtained if compared with others (Heat on resonator, surroundings, and cooling water). The Sankey diagram to ilustrate how big portion of exergy, energy totaly converted to be work or acoustic power in this case.

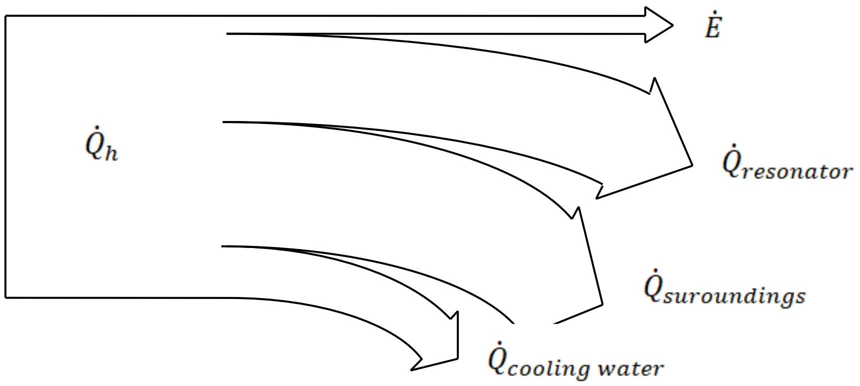

Figure 12. The Sankey Diagram of Conversion Thermal Energy to Acoustic and Losses Energy

4. Conclusion

Based on this result, we can conclude that the sound power at the optimal tilt angle of 90° is 10.7 W. Then the minimum is found at 0° and is 0.5 watts. It can be determined that the influence of the phase difference is large. The next researcher should do the following investigation on the analysis that the phase difference has a large effect on the horizontal positioning, resulting in a worse value compared to the vertical position. The highest SWTE efficiency is achieved with a cavity length of 390 mm, which is 5.5% efficient. It can be concluded that the shorter the cavity length, the higher the efficiency of SWTE.

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