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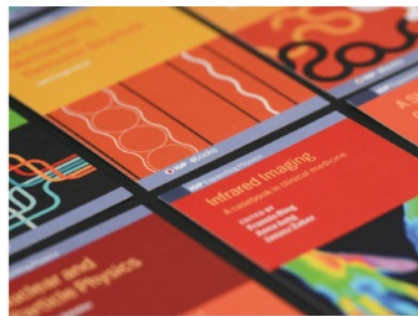
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## Numerical study of the influence of radius stack on the low heating temperature and efficiency of traveling wave thermoacoustic engine

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## Numerical study of the influence of radius stack on the low heating temperature and efficiency of traveling wave thermoacoustic engine

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**Abstract.** Thermoacoustic is one of the technological sciences that utilizes thermodynamics and acoustic waves. The thermoacoustic device is divided into two, namely the thermoacoustic engine that converts heat energy into acoustic waves, and the heat pump used to pump heat from low temperature reservoirs to higher temperatures by utilizing acoustic waves. This study examines the numerically of the effect of radius stack on the efficiency and the value of low heating temperature of thermoacoustic engine. This study use the fortran application with two codes, the first coding to get the value of stability limit, one of that is a low heating temperature. And to get the efficiency value, use the second code, which one of the result is the coding to get the value of coefficient of performance. As a result, the highest level of efficiency is when the stack radius has a size of 0.07 mm which reaches 57% while the lowest heating temperature value is reached when the stack has a radius of 0.12 mm which is 124 °C. So from this result, it can be seen that there is an influence of radius stack on the efficiency and low heating temperature of the thermoacoustic engine.

### 1. Introduction

The classification of geothermal system by Hocheisten in 1990 divided in to three parts. 1.) Geothermail system that has low enthalphy < 125°C, 2.) Geothermal system that has medium enthalphy 125°C – 225 °C and last 3.) Geothermal system that has high enthalphy > 225°C. Indonesia's system geothermal is hydrothermal that has high temperature > 225°C, and also has medium temperature 125°C – 225 °C, In Indonesia and oversea both of these system have been developed as geothermal power generation because the potential of geothermal energy in Indonesia is great, it's very large about 30%-40% of the most geothermal energy in the world that can prduce power 27500 MW [1]. Geothermal power generation only use the heat criteria at high and medium temperatures so that for criteria in low temperatures (< 125°C) it's still can not be utilized. To utilize heat criteria in low temperature we need to use an technology that can convert geothermal energy in low temperature to another energy, for example acoustic energy or we can call it thermoacoustic, where thermoacoustic technology is combination between thermodynamic and acoustic wave.

Thermoacoustic is one of science technology that investigate the relation between acoustic wave and heat energy, more pricesely its discuss about the conversion energy from heat energy to the acoustic wave, or conversion from acoustic wave to the heat energy [2]. Based on the type of wave that used in thermoacoustic technology, its divided in to two i.e: (a) standing wave (b) traveling wave [3]. Thermoacoustic has tools component that use to generate the effect of thermoacoustic, that call



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thermoacoustic device [4]. Thermoacoustic device divided in to two i.e : (a) Thermoacoustic heat pump / Cooler; this device is used to pump the heat energy from a lower temperature heat reservoir to a higher temperature heat reservoir (b) Engine / Prime mover; this device is used to convert heat energy to the acoustic energy. Thermoacoustic phenomena occurs when acoustic wave propagate in a narrow tube where the gas inside of the tube has interaction with the wall of the tube. As a result of these heat interactions, the conversion energy between heat power and acoustic power occurs. By using this energy we can construct a thermoacoustic engine [5]. Then this acoustic energy can be used as a power generation or cooler.

There many research about thermoacoustic technology use standing wave still done, one of the research is in 2013, Normah developed portable thermoacoustic heat engine that can convert energy from the combustion process of biomass to the acoustic power, the working gas is air at a pressure 1 atm. As a result from this research has efficiency 1,7%, and the pressure amplitude in engine 101 kPa. The generated acoustic power on the stack is 50.67 W and the velocity of heat supply to the stack is 2952,9 W [6]. When we want to increase the efficiency, the device that has general effect in the thermoacoustic system is engine, and looped resonator tube. Both of these are needed to increase the efficiency [7]. However, it's not necessarily when we get high efficiency then we also get the lowest heating temperature to. So, the parameters from the thermoacoustic engine will affect to the value of low heating temperature and efficiency. Include the radius of stack.

Based on the various problems describe in above, it is necessary to find the value of low heating temperature and efficiency as a result when we combine the parameters of radius stack, so that the value of lowest heating temperatures and highest efficiency will be known. The purpose of this research is to know the effect of radius stack on low heating temperature and efficiency of thermoacoustic engine using numerical calculation.

## 2. Method

### 2.1 Calculation Model

In figure (1) shows the scheme of calculation model. Parameters value from these design like length of tube, denote as  $L_{loop} = 2.8$  m, inner diameter is 40 mm, this looped tube filled by working gas helium at a pressure 0.51 Mpa. There is one thermoacoustic engine inside of tube. Its composed by one hot heat exchanger and one ambient heat exchanger, and thermal buffer tube.

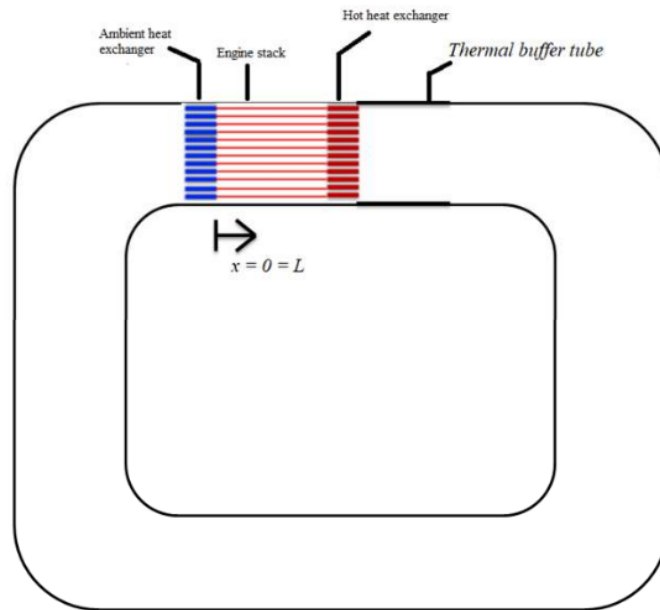
The length of stack is about 40 mm as the circle channels, radius of these channels in engine stack made as independent variable to find is there has influence about the radius of stack with the efficiency and low heating temperature of the system thermoacoustic.

Temperature in the hot heat exchanger and ambient heat exchanger continuously denote as  $T_H$  and  $T_A$ . The value of  $T_A$  in numerical calculation on set 301 K. Then the value of  $T_H$  will be obtained of stability limit calculation where the various radius stack will be using one by one to find the lowest heating temperature. Every hot heat exchanger has been modeled as a series of flat plates stack, and has space between the plates about 1.0 mm and height about 10 mm. There is a thermal buffer tube space after the part of hot heat exchanger

### 2.2 Efficiency

Given figure (2) a scheme of thermoacoustic engine from thermodynamic stand point. Subscripts  $e, A, H$  continuously define the engine stack, ambient heat exchanger, and hot heat exchanger. For example  $\dot{W}_{e,A}$  show as acoustic power at the end of ambient heat exchanger of engine stack demonstrate when the temperature  $T_H$  passing critical value, the working gas inside of the tube, also inside in the stack spontaneously will be oscillate [8]. As a result, there are traveling wave generated along the looped tube and transport energy. Acoustic power  $\dot{W}_{e,A}$  that produce from traveling wave is a input of the end ambient temperature of the engine stack and strength then in the engine stack. Consequently that is the advantageous from the acoustic power of the engine stack,  $\Delta\dot{W}_e$  shown in this equation [9]:

$$\Delta\dot{W}_e = \dot{W}_{e,H} - \dot{W}_{e,A} \quad (1)$$



**Figure (1):** The scheme of thermoacoustic engine

Then to amplify the acoustic power the heat exchanger need to provide acoustical thermal power  $\dot{Q}_H$ . Because of that, the efficiency of the engine can be shown by this equation [10] [10] :

$$\eta_e = \frac{\Delta \dot{W}_e}{\dot{Q}_H} \tag{2}$$

In this research we calculate the second law efficiency of engine stack. The second law efficiency can be define as equation [7] :

$$\eta_{2,e} = \frac{\eta_e}{\eta_{carnot}} \tag{3}$$

### 2.3 Calculation Procedure

The calculation of this research can be describe as follows:

1. The radius of flow channels from engine stack  $r_e$  with variation value 0,07 mm – 0,024 mm, the value of  $L/L_{loop}$  is also on set. Low temperature in the end of heat exchanger  $T_H$  is one of the result from stability limit calculation that we also search for. Then the value of ambient temperature  $T_A$  is on set 301 K.
2. The condition of stability limit where the spontaneous gas oscillation becomes neutral was calculate used matrix transfer method that was explained in the previous chapter. The parameters as a stability limit results is :  $T_H, \omega, P_{e,A}, U_{e,A}$ . Should be noted that the value of gradient temperature along the engine stack, and thermal buffer tube assumed to be linear [11].
3. By using the value  $T_H, \omega, P_{e,A}, U_{e,A}$  so the calculation of pressure and velocity in the end of stack is call  $(P_{e,H}, U_{e,H})$  can be calculated
4. Combination that was obtain from pressure and velocity have been used to calculate acoustic power in the end of engine stack  $(\dot{W}_{e,A}, \dot{W}_{e,H})$ . Then, the acoustic heat power in the final heat of the



engine stack  $\dot{Q}_H$  was calculate, by using the calculation of  $\dot{W}_{e,H}$ . Should be note, the enthalpy flow along the engine stack has been obtain in step three

5. These calculation results ( $\dot{W}_{e,A}, \dot{W}_{e,H}, \dot{Q}_H$ ) are substituted in equation 3-7 to evaluated  $\eta_e, \eta_{2,e}$ .

### 3. Results and Discussion

Setiawan also has research in 2015 he construct and examine the standing wave thermoacoustic engine used straight tube resonator there is stack inside of the straight tube, hot heat exchanger, ambient heat exchanger, the working gas is air at a pressure 1 atm and the ambient temperature is 27°C. The result of these research is the efficiency is about 1.4%. Setiawan said that we need to give many effort to increases the efficiency and improve the perfor mance of the prime mover /engine [2]. We can see the reasearch by Setiawan get the low efficiency when used the standing wave, to increases the efficiency of the thermoacoustic engine we can utilize the traveling wave [7]. In this research we try to get the best efficiency by comparing the radius stack and utilize the traveling wave thermoacoustic engine.

Based on the result of numerical calculation figure 2 we can see the value of lowest heating power that obtained when the radius stack is 0.12 mm. That is because in figure 3 we can see that the value of phase difference when the radius stack 0.12 mm is in low value, i.e approach 27 degree. This value can be categorized as a phase difference which approaches the traveling wave, so the dissipation is small and the heat temperature to oscillate is also small.

In this chapter, second low efficiency  $\eta_{2,e}$  and low heating temperatures  $T_H$  was calculated numerically. Then, the efficiency of thermoacoustic energy conversion will be explain. In this research the examine parameters is engine stack radius. In the case energy conversion at the egine stack , the heat energy is covert to the acoustic energy. As the result, acoustic power can be generated.

The results of numerically calculation with the one wavelength mode ( $\omega/2\pi \sim 360$  Hz), shown in the figure 4. These results is indicates that  $\eta_{2,e}$  from the thermoacoustic engine depend on the radius of stack (r). Maximum value of  $\eta_{2,e}$  is 57 % was obtained when the value of radius stack is 0.07 mm. This value is 4 times higher efficiency when the radius stack is 0.24 mm And the value of lowest heating temperature  $T_H$  is 124 °C was obtained when the r = 0.12 mm. This value 12% lower than  $T_H$  when the radius stack is 0.07 mm. (141°C) and 12 % lower than  $T_H$  when the radius stack is 0.024 mm (147°C), therefore it can be assumed that the selection of right radius is very important to get high efficiency and low heating temperature. In this calculation we calculate the second low efficiency from engine stack  $\eta_{2,e}$ . Where  $\eta_e$  is heat efficiency, and then  $\eta_{Carnot}$  is the up thermodynamic value of  $\eta_e$ . (Equation 2) and  $\eta_{Carnot}$  can be define as follows:

$$\eta_{Carnot} = T_H - T_A / T_H \quad (4)$$

Here,  $T_H$  is heat temperature and  $T_A$  is ambient temperature.  $\Delta \dot{W}_e$  genertaed acooustic power inside of *stack* and  $\dot{Q}_H$  is heating power in the end of stack. Other than acoustic power, the value of caused  $\dot{Q}_H$ , its also influence by  $\dot{Q}_d$ . The value of  $\dot{Q}_H$  and  $\dot{Q}_d$  can be found by using equation [9][12]:

$$\begin{aligned} \dot{Q}_H = & -\frac{1}{2} A \operatorname{Re}[g_b P \bar{U}] - \frac{1}{2} A \operatorname{Im}[g_b P \bar{U}] \\ & + A \frac{\rho_m c_p |U|^2}{2\omega(1-\sigma^2)|1-\chi_v|^2} \operatorname{Im}(\chi_\alpha + \sigma \tilde{\chi}_v) \frac{dT_m}{dx} + (Ak \\ & + A_{solid} k_{solid}) \frac{dT_m}{dx} \end{aligned} \quad (5)$$

$$\dot{Q}_d = A \frac{\rho_{mss} c_p |U|^2}{2\omega(1-\sigma^2)|1-\chi_v|^2} \operatorname{Im}(\chi_\alpha + \sigma \tilde{\chi}_v) \frac{dT_m}{dx} \quad (6)$$

Based on equation (14)  $\eta_{2,e}$  depend on  $\eta_e$  and  $\eta_{Carnot}$  as the explanation above, the highest  $\eta_{2,e}$  is reaches in radius 0.07 mm i.e 57%. The reason of that high  $\eta_{2,e}$  can be seen in equation 3. Based on that equation, the value of  $\eta_{2,e}$  will be high when the  $\eta_e$  is also high, and the  $\eta_{Carnot}$  is low. Based on figure 5 we can see that the reason why  $\eta_{2,e}$  being high, that because the highest  $\eta_e$  Based on was reach when the radius is 0.07 mm i.e 15%. Then, the value of  $\eta_e$  will be high its causes by high value  $\Delta W_e$  and small value of  $\dot{Q}_H$  (Equation 2)

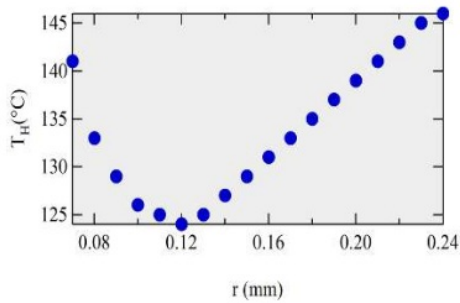


Figure 2  $T_H$  as a function r

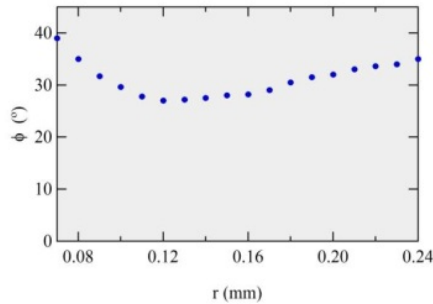


Figure 3 difference phase as a function r

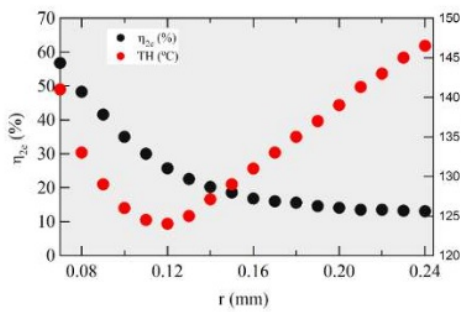


Figure 4 :  $\eta_{2,e}$  and TH as a function of r

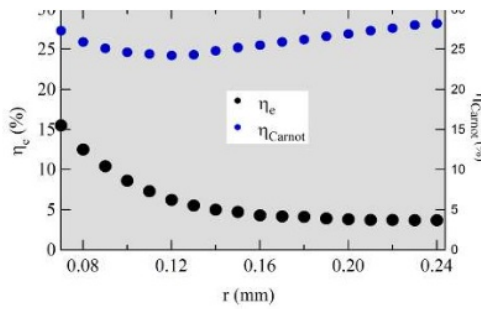


Figure 5  $\eta_e$  and  $\eta_{Carnot}$  as a function of r

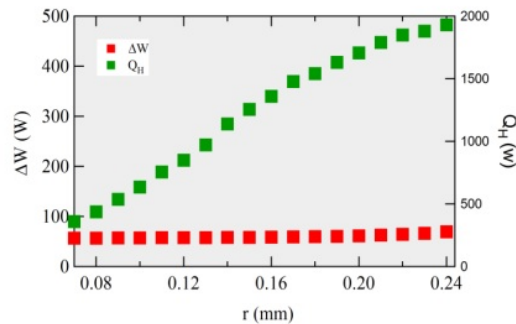


Figure 6  $\Delta W$  and  $Q_H$  as a function of r

#### 4. Conclusion

Based on numerical calculation the lowest heating temperature to makes thermoacoustic engine work is 124C ins radius 0.12 mm. That temperature is the low geothermal energy which was originally wasted, can be utilized by using thermoacoustic engine in this research the highest efficiency is reach when the radius stack in 0.07mm i.e 57%. . This efficiency is the highest value from previous research.

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