

Experimental review of a travelling-wave thermoacoustic system device

By Indah Kharismawati

PAPER • OPEN ACCESS

Experimental review of a travelling-wave thermoacoustic system device

6

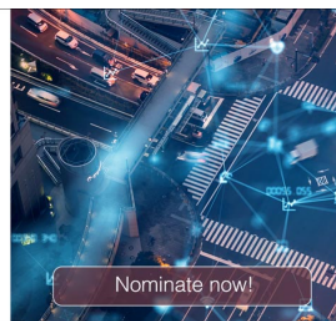
To cite this article: I Kharismawati *et al* 2021 *J. Phys.: Conf. Ser.* **1869** 012152View the [article online](#) for updates and enhancements.**The Electrochemical Society**

Advancing solid state & electrochemical science & technology

The ECS is seeking candidates to serve as the **Founding Editor-in-Chief (EIC) of ECS Sensors Plus**, a journal in the process of being launched in 2021

The goal of ECS Sensors Plus, as a one-stop shop journal for sensors, is to advance the fundamental science and understanding of sensors and detection technologies for efficient monitoring and control of industrial processes and the environment, and improving quality of life and human health.

Nomination submission begins: May 18, 2021



Experimental review of a travelling-wave thermoacoustic system device

I Kharismawati*, W N Achmadin and M M Trianggono

IKIP PGRI Jember, Jl. Jawa No.10 Jember 68121, Indonesia

*indahkharismawati@ikipjember.ac.id

Abstract. The thermoacoustic travelling wave device system has been designed and we have tested, this thermoacoustic device consists of loud-speakers as a sound wave source with a capacity of 120W, branched-tubes resonator, and loop-tube resonator that have a regenerator with a length of 8 cm placed inside loop-tube. Regenerator is made of acrylic material which has a size of 1 mm and the distance between pores and other pores also has a distance of 1 mm. The performance of the thermoacoustic travelling wave device is observed from the temperature changes it has and is reflected in how much changes in cold reservoir temperature and hot reservoirs it can achieve. The results of the experiments obtained will be analyzed in the form of temperature charts showing temperatures in hot reservoir and cold reservoir as a function of time. The temperature difference between the two sides of the regenerator reaches 26,3°C with details of the temperature rise of the heat side of the regenerator (T_h) up to $\Delta T_h = 13,4^\circ\text{C}$ and the temperature drop of the cold side of the regenerator (T_c) down to $\Delta T_c = 12,9^\circ\text{C}$.

1. Introduction

The state of the global society that implements advanced technologies as it is today makes it easier for a person to get something very quickly whenever and wherever they are. From this, many benefits, for example, that were difficult in the past, are now very practical. As with flicking your fingers, it's all going to be easy. This is supported by rapid technological advances, so technology-based companies are racing to create highly sophisticated technologies, which ultimately encourage consumers to race to get them. The development of existing technology is sure to have a negative effect on the environment [1]. With the problem of environmental destruction so that humans are required to find and develop a wide range of alternative technologies that are more efficient and have no impact on the environment, one of them thermoacoustic technology. The thermoacoustic advantage is that the construction is relatively simpler and the availability of medium of work is abundant so that the manufacture requires a relatively cheap cost. It uses air mediums and noble gases, not using hazardous mediums such as CFCs and HFC. So there is no negative impact on the environment [2].

Thermocoustic is a field associated with phenomena where temperature differences can evoke sound waves, and conversely sound waves can produce temperature differences. Sound waves in the gas contain the effect of changes pressure, motion, and temperature [3]. When the sound creeps in small spaces, the moving calorific will also flow to and from the walls of the space. The combination of all these movements will produce phenolytic phenomena or effects. The tool used to cause thermoacoustic effects is referred to as a thermoacoustic device [4].



Research on a travelling wave thermoacoustic refrigerator was pioneered by Yazaki et al [5]. They demonstrated an acoustic coolant that applies the Stirling cycle experienced by the gas traveled by travelling wave in a loop tube [6], numerically modeling two different approaches to temperature gradient integration inside thermocoustic regenerators. Thermocoustic calorific pumps can produce both cooling and heating with high temperature susceptibleness. As a coolant, thermocoustic heat pumps are capable of producing temperatures of $-65\text{ }^{\circ}\text{C}$ [7]. While Bassem et al [8] designed and tested a thermoacoustic refrigerator travelling wave type with a structure consisting of a resonator straight-tube and a loop-tube. By using linear motor as a source of sound and nitrogen gas that has a pressure of $0,5\text{ MPa}$ ($\pm 5\text{ atm}$), they can lower the temperature to 232 K . Ueda et al [9] have conducted research using a regenerator with a length of 50 mm , consisting of a stainless steel mesh, placed in a loop-tubes. The position and radius of the regenerator have been numerically optimized with a r_{rege}/δ_k is $0,19$ and significantly affects refrigerator performance.

Research on thermoacoustic refrigerator travelling wave type has also been conducted in Indonesia. Setiawan [10] has explained about the manufacture and initial testing of a thermoacoustic refrigerator device travelling wave type. Obtained a temperature drop of $6,2\text{ }^{\circ}\text{C}$ using a regenerator of a 40 mesh/inch stainless-steel wire material and using electric power input loudspeaker 66 W . Setiawan et al [11] studied the large dependence of temperature reduction on hydraulic regenerator fingers used in travelling wave thermoacoustic refrigerator devices. It was obtained that there was an optimum hydraulic finger that resulted in the largest drop in temperature. They obtained a maximum temperature drop of $18,7\text{ }^{\circ}\text{C}$ (i.e. from $28\text{ }^{\circ}\text{C}$ down to $9,3\text{ }^{\circ}\text{C}$) when using a regenerator with a hydraulic finger of $0,10\text{ mm}$ and a sound frequency of 30 Hz (thermal penetration depth of $0,5\text{ mm}$).

2. Method

Travelling-wave thermoacoustic device that we have designed it consists of loud-speakers as source of sound waves with a capacity of 120 W , branched-tubes resonator, and loop-tube resonator that have a regenerator with a length of 8 cm placed inside loop-tube as shown in (Figure 1). This resonator tube is made of polyvinyl chloride (PVC) material, and this PVC tube has a diameter of $5,25\text{ cm}$ with a loop-tube length of 240 cm .

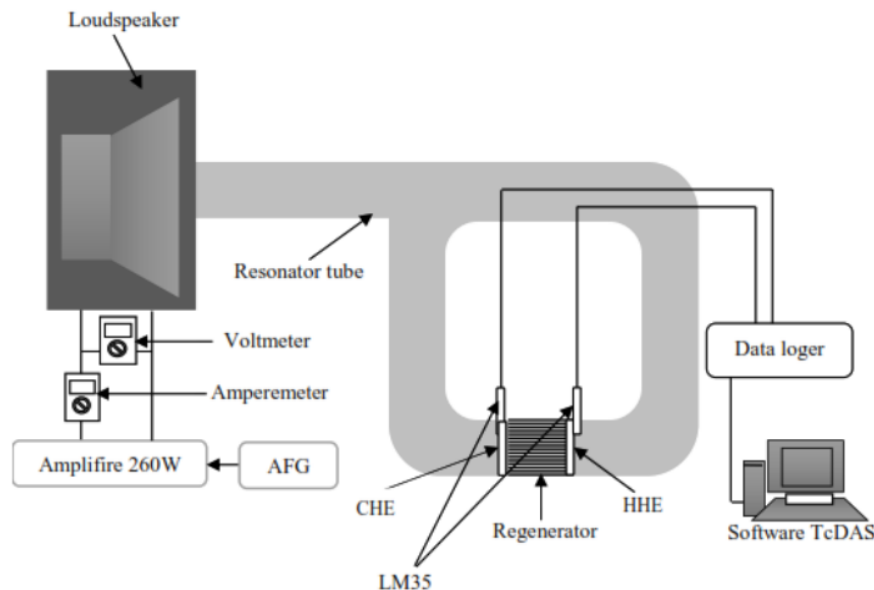


Figure 1. Design of a travelling-wave thermoacoustic device.

Regenerator position characteristics have been optimized numerically and are made of porous acrylic material. The pores diameter of the acrylic material in the regenerator has a size of 1 mm and the distance between the pores is 1 mm. The process of making this regenerator has used laser cutting which is operated via a computer. Before starting the cutting process using laser cutting, the laser cutting program is first set according to the material to be cut so that the laser cutting produces perfect cuts. The regenerator pattern which is saved in graphic format is opened in the laser cutting program which is used to determine the direction of laser movement. Next, a regenerator will be produced in the form of a porous circular strip.

Hot heat exchanger (HHE) and cold heat exchanger (CHE) is an important component which functions to dissipate heat in the hot resonator area into the environment through a fluid medium. The material used for HHE and CHE must have good thermal conductivity so that they can absorb heat quickly. The materials used are copper pipes with a diameter of 4,7 mm and copper plates with a thickness of 1 mm. The copper plate is cut into rectangles 6 cm long and 2 cm wide. Then, they were given 15 holes to place copper pipes with fluid flowing as a heat waster into the environment. The chopper which has been cut is then arranged as high as 6 cm and given a distance between the layers of 1 mm. After that a copper pipe is installed in each hole in the copper plate, then the hot heat exchanger is placed in a box made of acrylic arrangement.

The temperature detection system consists of 2 digital thermometers with a temperature sensor (thermocouple) type IC-LM 35 coupled with a data logger, then this data logger is connected to a computer to display the measurement data. The use of data loggers can display data on a computer in real-time and the data can be saved in txt format. The data displayed by this digital thermometer has three-digit number with a precision of 0,1 °C. This thermocouple is installed near the ends of the regenerator.

Preliminary experiments to determine the frequency of resonance by using win scope. And in the second experiment, the temperature of both reservoirs was measured using a digital thermometer (LM-35). It can be observed how much the reservoir temperature changes. The next experiment was carried out by installing an HHE heat exchanger in a hot reservoir. In this case, it will be observed how big the temperature change of the two reservoirs is, so that the temperature change can be compared with the presence or absence of the HHE heat exchanger. The performance of this traveling wave thermoacoustic device can be seen from the change in temperature it has and is reflected by how much changes in the temperature of the cold reservoir and the hot reservoir can be achieved. Furthermore, the experimental results that have been obtained will be analyzed using the graphical method in the form of a temperature graph showing the temperature in the hot and cold reservoirs as a function of time. In this case describes the process of changing the temperature of the hot reservoir air and also the increase in temperature of the cold reservoir over time of operation of the device, including the rate of temperature change and how much the temperature change is achieved.

3. Calculation method

The similarities of momentum and continuity in a flow pipe tube are as follows [12];

$$\frac{dP}{dx} = -\frac{1}{A} \frac{i\omega\rho_m}{1 - \chi_v} U \quad (1)$$

$$\frac{dU}{dx} = -\frac{i\omega A(1 + (\gamma - 1)\chi_a)}{\gamma p_m} P + \frac{\chi_a - \chi_v}{(1 - \chi_v)(1 - \sigma)} \frac{1}{T_m} \frac{dT_m}{dx} U \quad (2)$$

where ω is the frequency of the angle of the sound wave, A is the area of the cross section of the tube pipe tube, ρ_m is the average density, γ is the specific heat ratio, σ is the Prandtl number, p_m is the average pressure, and T_m is the average temperature. x represents coordinates in an axial direction. Because ρ_m ,

γ , σ depend on T_m , the value of the air physical property is referred to the physical property data value. P represents a pressure fluctuation and U represents a fluctuation in flow speed.

$$\chi_\alpha = \frac{2J_1(Y_\alpha)}{Y_\alpha J_0(Y_\alpha)}, \quad \chi_v = \frac{2J_1(Y_v)}{Y_v J_0(Y_v)} \quad (3)$$

$$Y_\alpha = (i-1)\sqrt{\omega\tau_\alpha}, \quad Y_v = (i-1)\sqrt{\omega\tau_v} \quad (4)$$

where J_1 and J_0 is Bessel function, and sequentially τ_α and τ_v are defined as $\tau_\alpha = r^2/2\alpha$ and $\tau_v = r^2/(2\nu)$, where α is thermal diffusivity and ν is kinematic viscosity. Each $\omega\tau_\alpha$ and $\omega\tau_v$ is associated by $\sigma = \nu/\alpha$ as $\frac{\omega\tau_\alpha}{\sigma} = \omega\tau_v$ [13].

The enthalpy flows along the regenerator and resonator tube should remain constant because they are assumed to be isolated, hence the enthalpy flow can be written as [14];

$$\dot{H} = \frac{A_{loop}}{2} Re \left[P\tilde{U} \left(1 - \frac{\chi_\alpha - \chi_v}{(1+\sigma)(1-\chi_v)} \right) \right] + \frac{A_{loop}\rho_m c_p |U|^2}{2\omega(1-\sigma^2)|1-\chi_v|^2} \text{Im}[\chi_\alpha - \sigma\tilde{\chi}_v] \frac{dT_m}{dx} - (A_{solid1}k_{solid1} + A_{solid2}\varepsilon k_{solid2}) \frac{dT_m}{dx} \quad (5)$$

where C_p is a specific heat constant of gas oscillations. A_{loop} is a cross-sectional area of the loop-tube, A_{solid1} and k_{solid1} is a cross-sectional area and thermal conductivity of the regenerator container layer. A_{solid2} and k_{solid2} are the cross-sectional and thermal conductivity areas of solid materials consisting of regenerators. ε is an effective thermal conductivity reduction factor of multiple layers of regenerator plate. The value of ε used is 0.1 [15].

Enthalpy flow \dot{H} and acoustic power flow \dot{W} can determine heat flow on thermoacoustic, the equation is as follows;

$$\dot{Q} = \dot{H} - \dot{W}, \quad \text{where} \quad \dot{W} = \frac{A_{loop}}{2} Re[PU] \quad (6)$$

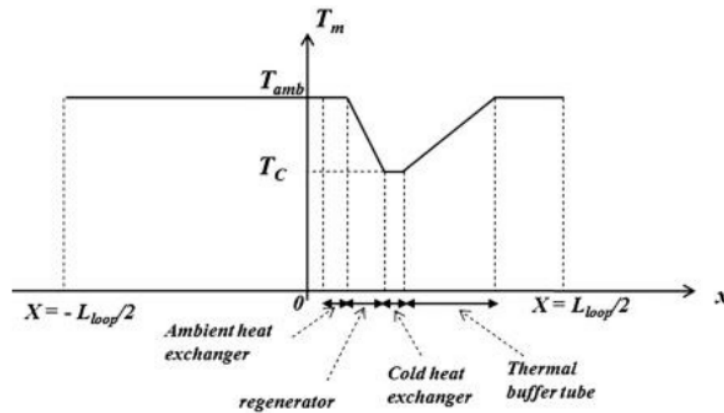


Figure 2. Temperature distribution close to cold heat exchanger [8].

The refrigerator power is defined as the amount of heat flow at the cold end of the regenerator (Figure 2), this is equal to the sum of the two heat flow components; heat flow from cold heat exchanger to regenerator and heat flow from thermal buffer tube to cold heat exchanger. This can be stated as follows:

$$Q_C = \left| \dot{Q}_{x=L_H+L_{reg}} \right| \quad (7)$$

where L_{reg} is the regenerator length, the acoustic power W_{in} is defined as follows;

$$W_{in} = \left| \dot{W}_{x=-L_{loop}/2} - \dot{W}_{x=L_{loop}/2} \right| \quad (8)$$

The performance coefficient (COP) of the travelling-wave thermoacoustic refrigerator can use Q_c and W_{in} equations, so that they can be stated as follows;

$$COP = \frac{|\dot{Q}_{x=L_H+L_{reg}}|}{|\dot{W}_{x=-L_{loop}/2} - \dot{W}_{x=L_{loop}/2}|} \quad (9)$$

$$COP = \frac{Q_c}{W_{in}} \quad (10)$$

16

4. Results and discussion

The results of the T_h and T_c temperature experiments over time during the operation of the thermoacoustic travelling wave device system were demonstrated by Fig.3. In this case, the operation is carried out with several variations in the sound frequency from 40 Hz to 49 Hz, the result of optimum frequency is 48 Hz. The optimum frequency obtained is estimated resonance frequency for the combined system between straight resonator tube and loop tube. The first the temperature of both sides of the regenerator is the same. Then when the sound wave generation system is activated, there is a change in the temperature of both sides. The heat side of the regenerator is the side that has a higher temperature than the initial temperature, and vice versa the cold side of the regenerator is the side that has a temperature lower than the original temperature. From the graph in (Figure 3), the heat side temperature of the regenerator (T_h) rises to $\Delta T_h = 13,4$ °C from the initial temperature of 29,3 °C, while the cold side temperature of the regenerator (T_c) drops to $\Delta T_c = 12,9$ °C from the initial temperature. So the temperature difference between the two sides of the regenerator is 26,3 °C.

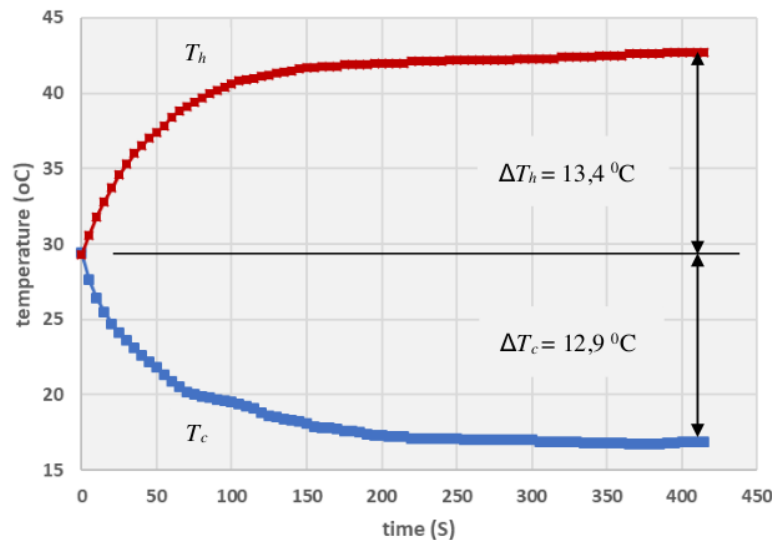


Figure 3. Graph of the results of the experiment on temperature changes over time.

In the resonator tube in the heatside, the pressure will increase so that from the adiabatic nature of the gas, the temperature increases. On the coldside side, the pressure is reduced because the gas on this side is pushed to the heatside, and the temperature on the coldside will also drop. This theory could explain

why temperature oscillations can occur during the movement of sound waves occurring inside the resonator tube.

When the sound wave generation system has not been activated, the gas particles (medium) in the regenerator are silent. While when the sound source is activated, gas particles will oscillate while moving the calorific from the cold side (T_h) to the hot side (T_c). This phenomenon is called thermocoustic. The following thermocoustic process illustrations are used to facilitate the physics understanding of thermocoustic phenomena. The gas package is a volume of gas small enough that the pressure and temperature are uniform but large enough to review the macroscopic properties of the gas. The regenerator is assumed to be a parallel plate arrangement where the gas package moves back and forth in a parallel direction, then the gas package has the speed and pressure as a result of the sound travelling wave.

The thermocoustic heat pumping process begins when acoustic waves cause the gas inside the regenerator to move into the heatside, the gas will be compressed and the pressure increases. This compressed gas will be hotter than the wall of the nearby regenerator so that it releases heat to the regenerator and the volume of the gas shrinks. As the sound wave continues its cycle, the gas moves back to the coldside where the pressure is lower, in which case the gas becomes looser and colder than the nearby regenerator wall, so that it absorbs the calorific from the regenerator wall and expands. This cycle continues to repeat and the effect is the transfer of heat from the cold part to the heat part of the regenerator.

5. Conclusion

Experimental research on the thermocoustic travelling wave device system has been conducted to have the radius and position of the regenerator optimized by calculation. The performance of the built-in thermocoustic travelling wave system has been operated. The temperature difference between the two sides of the regenerator reaches 26,3 °C with details of the temperature rise of the heat side of the regenerator (T_h) up to $\Delta T_h = 13,4$ °C and the temperature drop of the cold side of the regenerator (T_c) down to $\Delta T_c = 12,9$ °C. From these results, this thermocoustic travelling wave device system can operate properly and can be used as an alternative as a cooler and heater.

Acknowledgment

We would like to thank IKIP PGRI Jember for supporting this research and for its financial support.

References

- [1] Astuti A D 2018 Implikasi Kebijakan Indonesia Dalam Menangani Kasus Pencemaran Lingkungan Oleh Pt. Freeport Terhadap Keamanan Manusia Di Mimika Papua *J. Int. Relations* **4** 547–55
- [2] Babu K A and Sherjin P 2017 A Critical Review on Thermoacoustic Refrigeration and its Significance *Int. J. ChemTech Res.* **10** 540–52
- [3] Avent A W and Bowen C R 2015 Principles of thermoacoustic energy harvesting *Eur. Phys. J. Spec. Top.* **224** 2967–92
- [4] Kiranmayee T and Kumar D M L S D 2017 DESIGN & FABRICATION OF THERMOACOUSTIC *Int. J. Emerg. Technol. Innov. Res.* **4** 407–10
- [5] Yazaki T, Biwa T and Tominaga A 2002 A pistonless Stirling cooler *Appl. Phys. Lett.* **80** 157–9
- [6] Jensen C, Raspet R and Slaton W 2006 Temperature gradient integration in thermoacoustic stacks *Appl. Acoust.* **67** 689–99
- [7] Tijani M E H, Zeegers J C H and De Waele A T A M 2002 Construction and performance of a thermoacoustic refrigerator *Cryogenics (Guildf)*. **42** 59–66
- [8] Bassem M M, Ueda Y and Akisawa A 2011 Design and construction of a traveling wave thermoacoustic refrigerator *Int. J. Refrig.* **34** 1125–31
- [9] Ueda Y, Mehdi B M, Tsuji K and Akisawa A 2010 Optimization of the regenerator of a traveling-wave thermoacoustic refrigerator *J. Appl. Phys.* **107**

- [10] Setiawan I 2014 Pembuatan Piranti Pendingin Termoakustik Gelombang Berjalan *Prosiding Seminar Nasional Fisika Terapan IV* pp B10–4
- [11] Setiawan I, Fadly M N M and Utomo A B S 2017 Experimental Demonstration of the Dependence of Temperature Decrease on the Hydraulic Radius of Regenerator in a Traveling Wave Thermoacoustic Refrigerator *J. Phys. Conf. Ser.* **820**
- [12] Rott N 1973 Thermally driven acoustic oscillations. Part II: Stability limit for helium *Zeitschrift für Angew. Math. und Phys. ZAMP* **24** 54–72
- [13] Utami S W, Farikhah I, Khoiri N, Patonah S and Kaltsum U 2019 Kajian Numerik Pengaruh Jari-Jari Stack Terhadap Suhu Rendah Mesin Termoakustik Gelombang Berjalan *Prosiding Seminar Nasional The* pp 23–30
- [14] Swift G W 2017 *Thermoacoustics: A Unifying perspective for some engines and refrigerators: Second edition*
- [15] Lewis M A, Kuriyama T, Kuriyama F and Radebaugh R 1998 Measurement of beat conduction through stacked screens* *Adv. Cryog. Eng.* **43** 1611–8

Experimental review of a travelling-wave thermoacoustic system device

ORIGINALITY REPORT

17%

SIMILARITY INDEX

PRIMARY SOURCES

1	repository.warmadewa.ac.id Internet	132 words — 5%
2	etheses.whiterose.ac.uk Internet	55 words — 2%
3	repository.lppm.unila.ac.id Internet	51 words — 2%
4	Bassem, M.M.. "Design and construction of a traveling wave thermoacoustic refrigerator", <i>International Journal of Refrigeration</i> , 201106 Crossref	37 words — 1%
5	Amirin, Triyono, M Yulianto. "Experimental study of thermoacoustic cooling with parallel-plate stack in different distances", <i>IOP Conference Series: Materials Science and Engineering</i> , 2019 Crossref	33 words — 1%
6	lppm.ub.ac.id Internet	28 words — 1%
7	<i>Advances in Cryogenic Engineering</i> , 1998. Crossref	19 words — 1%

8 Artur J Jaworski, Xiaoan Mao. "Development of thermoacoustic devices for power generation and refrigeration", Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 2013 18 words — 1%

Crossref

9 Ikhsan Setiawan, Muhammad N M Fadly, Agung B S Utomo. "Experimental Demonstration of the Dependence of Temperature Decrease on the Hydraulic Radius of Regenerator in a Traveling-Wave Thermoacoustic Refrigerator", Journal of Physics: Conference Series, 2017 18 words — 1%

Crossref

10 Oday S. Mahmood, Abdul Mun'em A. Karim, Samir Gh. Yahya, Itimad D. J. Azzawi. "Miniaturized Traveling-Wave Thermoacoustic Refrigerator Driven by Loudspeaker: Numerical Design", International Journal of Air-Conditioning and Refrigeration, 2020 14 words — < 1%

Crossref

11 Maroua BEN NASR, Mohamed Mehdi BASSEM, Yuki UEDA, Amenallah GUIZANI. "Numerical investigation on a travelling wave thermoacoustic heat pump", Journal of Thermal Science and Technology, 2018 13 words — < 1%

Crossref

12 faculty.uobasrah.edu.iq 10 words — < 1%

Internet

13 Brijesh Prasad, Narendra Gariya, Varij Panwar, Pravin Patil, Pushpendra Kumar. "Analysis of porous polymer membranes using FEM software for sensing applications", Materials Today: Proceedings, 2020 9 words — < 1%

Crossref

14 eprints.whiterose.ac.uk 9 words — < 1%

Internet

-
- 15 Cryocoolers 12, 2003. 8 words — < 1%
Crossref
-
- 16 R D Ferdiani, M Manuharawati, S Khabibah. 8 words — < 1%
"Geometry material: Profile of creative thinking process of prospective teachers with reflector learning style in proposing and solving problems", Journal of Physics: Conference Series, 2021
Crossref
-
- 17 etd.cput.ac.za 8 words — < 1%
Internet
-
- 18 jurnal.uns.ac.id 8 words — < 1%
Internet
-
- 19 webistem.com 8 words — < 1%
Internet
-
- 20 www.springerprofessional.de 8 words — < 1%
Internet
-
- 21 W N Achmadin, I Kharismawati, M M Trianggono. 6 words — < 1%
"A measurement of various length of the stack on a standing wave thermoacoustic refrigerator", Journal of Physics: Conference Series, 2021
Crossref
-

EXCLUDE QUOTES ON
EXCLUDE BIBLIOGRAPHY ON

EXCLUDE MATCHES < 1 WORDS