Performance analysis of forced convection coolers using synthetic jets with variations in altitude from synthetic jets to heat sources

Muchammad Baihaqi Muslich¹, Damora Rhakasywi², M As’adi³ and Nur Cholis⁴
1,2,3,4Mechanical Engineering Study Program, Faculty of Engineering, Universitas Pembangunan Nasional “Veteran” Jakarta

1muchammadb@gmail.com

Abstract. Every electronic device has a disadvantage that is heat generated from the components contained in the device while operating. The heat that occurs during the process can affect the effectiveness of these electronic devices. The cooling fan is directed to a heat source from an electronic device with the aim of maintaining the device's performance temperature. However, the cooling fan used still has some disadvantages in terms of dimensions. Therefore, research on synthetic jets is carried out as an innovation in cooling. This study aims to find wave characteristics as a source. Optimum frequency selection to support cooling. As well as the ideal height of synthetic jets to heat sources. The method used in the research is direct and computer-based data retrieval for CFD. The use of triangular waves as a source of cooling with a frequency of 80 Hz at an altitude of 8 cm can reduce rapidly. However, the lowest final temperature comes from a height of 2 cm which is 28.1 °C.

1. Introduction
In an age of rapid technological development, electronic devices are devices used in almost all industries to control product quality and production processes, production automation and also data processing for research. Likewise in our daily lives, electronic devices are one of the important devices in supporting our quality of life. For example cellphones that are used to communicate, television for entertainment or get important news, cameras to capture important moments in our lives and many more household devices and personal devices that use electronic principles and components to be able to operate them.

Since it was first created until now electronic devices such as mobile phones and laptops, have undergone a very drastic change, especially in terms of dimensions. The dimensions of these electronic devices have narrowed according to human needs for convenience and practicality so they can support their mobility. Every electronic device has a disadvantage that is the heat generated from the components contained in the device during operation.

The heat that occurs during the process can affect the effectiveness of these electronic devices [1]. The cooling fan is directed to the heat source of the electronic device in order to maintain the temperature of the device's performance. However, the cooling fan used also still has some drawbacks in terms of dimensions. Synthetic jets present as an innovation of cooling systems in electronic devices. Synthetic jets are capable of producing unstable flow with a simple structure that makes it effective in convective heat transfer [2]. Synthetic jets have the potential to use electronic cooling, taking into account various wave forms for the purpose of increasing heat transfer [3].
Synthetic jet cooling increases the rate of heat transfer compared to other cooling techniques. Synthetic jets are made for single and multi-nozzle holes with the help of sound system vibrations [4]. Synthetic jets are potentially useful in electronic cooling. Synthetic jets can be studied numerically by considering various wave forms for the purpose of increasing heat transfer and compared with suitable stable air jets [5]-[7].

The effect of synthetic jets on the rate of heat transfer along a flat plate has been studied for laminar and cross-flow turbulence and at several interesting frequencies (0 <f <12.8 Hz) [8]. Through comparisons with previous work on the imping flow field of synthetic jets, this investigation highlights how the topology of the synthetic jet flow field overrides which is basically influenced by the heat transfer mechanism on the impingement plate [9], [10]. Where different work results will be obtained through variations in the distance between the plate and the exit from the nozzle [11]-[13].

Synthetic jet experiments have been carried out at Reynolds number equal to 5100 and Strouhal number equal to 0.024 varying the distance of the jet axis and nozzle to the distance of the plate [14]. Heat transfer in general can be achieved with synthetic jets, especially in sufficient jet distances between exits from the nozzle to the plate.

The heat transfer of an elliptic synthetic jet that affects an experimentally heated flat plate is investigated in a circular orifice shape [15]-[17]. The shape of the hole like a circle was chosen because the shape is quite common and has been widely used. Elliptical holes perform better than other shapes of holes such as square or triangle, this is mainly due to increased mixing and a large entrainment rate with elliptical holes [18]. Therefore, hole size and shape and operating parameters play an important role in the design of synthetic jets for certain applications.

Numerical simulations are used to find the optimal design for synthetic jets, calculations are realized by commercial software ANSYS Fluent [19], [20]. The numerical model is verified by comparing computational results with experimental results. Maximum synthetic jet characteristic speed and efficiency are located on the resonance curves at 87 Hz and 100 Hz, where the maximum characteristic speed and efficiency are plotted as a function of real source or power input [21]-[23].

To determine the effectiveness of synthetic jets as coolants, it is necessary to do research and testing based on the limits and formulation of the problem specified. Therefore, this study focuses on the characteristics of the variation of the height of the heat source and jet blow distance with the aim of finding the ideal jet blow distance to the heat source, the type of air flow produced, and the decrease in temperature of the heat source that occurs with variations in jet blow distance.

2. Literature Review

2.1. Wave

Waves are a form of change in momentum and energy at one point to another. Waves are also defined as vibrations that propagate through the medium [24]. Wave medium can be solid, liquid, or gas. For example, the rope, slinki, water, and air.

Based on the propagation medium, waves are divided into mechanical waves and electromagnetic waves. Mechanical waves are waves which in their propagation require propagation medium such as water waves, string waves and sound waves. While electromagnetic waves are waves that do not require propagation media such as light waves, radio waves, or waves in X-rays.

When based on its amplitude, waves are divided into stationary and traveling waves. Stationary waves are waves whose amplitude changes, as in the example of a guitar string being picked. As for the traveling wave, it is a wave whose amplitude is fixed at each point the wave travels.

An event in a stretched rope can show examples of transverse waves that occur. Waveforms consist of various kinds, including sinusoidal waves and non-sinusoidal waves. Sinusoidal waves are waves that have the same curve shape as the curve function sin θ against θ. Sinusoidal waves are simple waves that can be used for more complex waves. Sinusoidal waves can also be a mathematical function in the form of repetitive fine oscillations. This function often appears in mathematics, physics, signal processing, and electrical power engineering. For non-sinusoidal waves, a sinusoidal wave is a square wave and a
triangular wave. Square wave or square wave has a shape like its name, which is square. This wave has a symmetrical waveform with the same duration in the other half-box cycle (having regular intervals). While triangular waves or triangular waves are waves that have a linear rise and decrease in the X axis. With certain harmonic values, the two waves can be described by the Fourier series equation.

2.2. Fluid Flow
Fluid is part of changes in the shape of objects, including liquid, gas, plasma, or solid objects. Fluid has the ability to flow (or follow the shape of a place). The nature of the fluid that can follow the shape of the place due to the inability to resist the influence of shear forces \(^2\). Fluid gas does not have a fixed shape or volume. Gas will develop to fill all places or rooms. Because the liquid and gas phases do not maintain a fixed form, both have the ability to flow. Thus both are often referred to as fluids \(^2\).

Because of the nature of fluid that can flow, the fluid that flows has the form of flow that can be divided into two outlines, namely steady flow whose flow is not affected by changes in time so that the speed is constant at each point (no acceleration occurs) and non-steady flow which the flow changes in speed with time. According to the type of flow, fluid can be divided into three types of flow, namely laminar flow, transition flow, and turbular flow.

2.3. Heat transfer
Heat transfer is a field of science to determine the energy transfer that occurs due to the temperature gradient on an object or a material. Heat transfer can also be defined as the transfer of energy from one region to another due to differences in temperature from these regions from higher fluid temperatures to lower fluid temperatures. If seen as a branch of science, heat transfer is the science that predicts energy transfer that occurs due to temperature differences between objects or materials. The science of heat transfer not only tries to explain how heat energy moves from one object to another, but it can also predict the rate of heat transfer that occurs under certain conditions.

2.4. CFD (Computational Fluid Dynamic)
Computational Fluid Dynamic (CFD) is a method that can be used to study, estimate, and predict the nature of fluids, reactions, heat transfer, and fluid phenomena using mathematical equations. CFD is a way of modeling complex fluid flows by describing geometric shapes into cell forms consisting of discretion through computer media \(^2\). Fluid flow prediction using CFD is based on three things namely the Mathematical model (Navier-Stokes), numerical methods, and tools or software usage. The use of software in analyzing the characteristics of a fluid is needed, the software application used is CFD FLUENT\(^2\). There are three main stages in using CFD Fluent to show the characteristics of a fluid, namely: Pre-Processing, Processing, and Post-Processing.

2.5. Synthetic Jet
Synthetic jets are fluid jets that appear to be generated from periodic motion of a closed diaphragm from inside a cavity that is open from one or more walls \(^2\). Synthetic jets are streams with zero net net (zero-
mass) input produced by the harmonic motion of the membrane and out through the orifice gap \cite{20}. Synthetic jets operate in a simple, flexible membrane or called a diaphragm forming one end of a part of a closed space \cite{30}. Opposite of the vibrating membrane, is the jet nozzle or orifice plate. This moving membrane is an actuator with a zero net mass input value but can produce a non-zero net momentum output.

3. Research Methodology

3.1. Data Collection Procedure
Data was collected for 3600 seconds recorded using a TM-946 digital thermometer connected to a laptop with the Lutron801 application. The limits of the problem specified in conducting data retrieval are as follows.
1. Using triangular wave variations in the Test Tone Generator 4.5 application.
2. The frequency used is 80 Hz.
3. The variation of synthetic jet height to heat sources is 2, 4, 6, 8 and 10 cm.
4. Room test temperature interval after testing 26-28 °C.
5. The state of the closed door.
6. The temperature of the heat source is 60 °C.
7. Data processing is also done on a per minute basis.
8. Air flow simulation is performed using CFD Fluent.

Simulations using CFD FLuent are performed to obtain the type of air flow created from synthetic jets. This study focuses on the use of CFD Fluent to display the vorticity contours of synthetic jet flow and the turbulent intensity contours that are formed. The Boundary Condition in the simulation is as follows.

| Fluid Properties | Fluid | Air |
|------------------|-------|-----|
| Density | 1.225 kg/m³ | |
| Viscosity | 1.7884 x 10^-3 kg/m.s | |
| Cp | 1005.43 J/kg.K | |
| Thermal Conductivity | 0.0242 W/m.k | |
| Boundary Condition | Velocity Inlet | 1.7DF |
| Pressure Outlet | 0 Pa | |
| Heater | 60 °C | |
| Frequency | 80 Hz | |
| Amplitude | 1.7DF | |
| Height | 2, 4, 6, 8, 10 cm | |

4. Analysis and Discussion

4.1. Analysis based on trial equipment
Triangular waves or triangular waves are waves that have a linear rise and decrease in the X axis. Requires a longer time interval to the maximum peak point and towards the maximum valley point. Triangular waves are also non-sinusoidal waves obtained from the transformation of sine waves so that they resemble the shape of a triangle based on the value of the amplitude with respect to time units.

Based on the graph above, we can see the difference in the temperature of the temperature decrease in the heat source with various variations in altitude. The green line shows a decrease in heat source temperature faster than the others, the green line comes from synthetic jets 8 cm away from the heat.
source. Followed by a red line, where it comes from data obtained on synthetic jets with a height of 6 cm to the heat source.

Data on figure 3 is obtained per second up to 3600 seconds. At 8 cm and 6 cm heights can be the optimum distance using triangle waves with a frequency of 80 Hz. This is based on the decrease produced at these two heights better than the other heights. But the temperature of the heat source will be constant after 2000 seconds. This is true at all heights, so the drop graph is not as extreme as before and the temperature changes don't occur too large. The coldest final temperature produced by synthetic jets to heat sources with a height of 2 cm, which is equal to 28.1 °C.

![Figure 3. Decrease in temperature based on variations in altitude with seconds](image1)

![Figure 4. Decrease in temperature based on variations in altitude with minutes](image2)

From Figure 4, the height of the synthetic jet's 8 cm return to the heat source decreases rapidly compared to other heights based on calculations per minute. In addition to the height of 8 cm, the height of 6 cm also does a fairly fast cooling process based on per minute.

After the 40th minute, there was no significant cooling as before and the temperature tends to be constant. It's the same as the calculation based on seconds like before. The coldest final temperature is still obtained at an altitude of 2 cm synthetic jet against a heat source of 28.1 °C.

From the data and graphics above, it can be seen that a distance that is too close does not guarantee that the cooling process will run faster when compared to the higher one. It's just that the final temperature that can be reached the coldest is obtained at a height of 2 cm. This happens because the thermocouple used is only 1 point on the heat source, so the temperature reading is less than the maximum and only based on the temperature of the heat that propagates to the thermocouple point.

The use of triangular waves as input with a frequency of 80 Hz if it is influenced by variations in height does not produce too much difference between 1 height variation with other heights. Even cooling only lasts up to 2400 seconds or 40 minutes. This can be seen in graph 1 and graph 2 there is no decrease in temperature the same as before after that time. Both graphs tend to be constant up to 3600 seconds or 60 minutes. It could be because the wave character of the triangle itself if not at the right height will produce a cooling effect like the two graphs. Some additional support is still needed and further research is needed in order to get maximum results related to synthetic jets as cooling devices.

4.2. Airflow Simulation Using Fluent CFD

The use of CFD is done by analyzing the contour of instantaneous velocity, instantaneous vorticity, and turbulence-intensity by simulating using the CFD Fluent software. The triangle wave type is simulated using a frequency of 80 hz with variations in altitude from synthetic jets to heat sources at times of 10 seconds, 51 seconds and 120 seconds. The contour of the simulation results will be used to see the phenomena that occur in the cavity synthetic jet module with heat sink. In addition, synthetic jet
membrane suction and discharge contours are shown in one phase to show the flow phenomenon that occurs in the synthetic jet system itself against variations in altitude.

Based on graphs of temperature changes made in an experimental manner, the greatest temperature reduction occurred during the first six minutes until before the 40th minute or 2400th second. The cooling process took place. So that in simulations using CFD Fluent, simulations are carried out with a time of 360 seconds or equivalent to six minutes, with number of time steps 10 and time step size 36. 10 indicates that the simulation starts from 10 seconds to 36 times to 360 seconds, and spaced multiples of 10 such as 10, 20, 30, and so on from each iteration to be performed. 80 Hz frequency and triangle wave have been included in the User Defined Function (UDF) so that the simulation can be directly run.

Table 2. Vorticity with various height variations

| Height Variations | Vorticity Distribution |
|-------------------|------------------------|
| 2 cm              | ![Vorticity Image](image1) |
| 4 cm              | ![Vorticity Image](image2) |
| 6 cm              | ![Vorticity Image](image3) |
| 8 cm              | ![Vorticity Image](image4) |
| 10 cm             | ![Vorticity Image](image5) |

Table 3. Vector Velocity with a variety of height variations

| Height Variations | Vector Velocity Distribution |
|-------------------|-----------------------------|
| 2 cm              | ![Vector Image](image6) |
| 4 cm              | ![Vector Image](image7) |
| 6 cm              | ![Vector Image](image8) |
| 8 cm              | ![Vector Image](image9) |
| 10 cm             | ![Vector Image](image10) |

Table 2. shows the shape of the vorticity profile created on synthetic jets using triangle waves with a frequency of 80 Hz at various altitude variations. Interval of the first minute, vorticity occurs around the orifice that is created around the speaker membrane and on the right side of the environment above the flat plate. This is because at 60 seconds, the membrane undergoes a suction phase for a variety of altitude variations. Whereas the blowing phase was recorded to occur at 160 seconds with the flow of vorticity that occurred around the orifice, the membrane reaching the heat source at various height variations. The value for the largest vorticity for a triangle wave with a frequency of 80 Hz is indicated by the number $6.67 	imes 10^0$ at 160 seconds which is visible from the edge of the orifice when going to make a phase of blowing at a heat source with a height of 10 cm. The flow of air exhaled from the orifice against heat sources with various variations in altitude is then released into the environment. So that the flow of vorticity that is created is still formed until released into the environment after pounding a heat source with various variations in altitude.

The red color on the legend and the profile shape during the simulation shows the greatest value that occurs in synthetic jet simulations with various variations in altitude. While the dark blue color indicates the lowest value that occurs when synthetic jet simulation with heat sources at various altitude variations is done.

Table 3. shows the shape of the velocity vector profile created on synthetic jets using triangle waves with a frequency of 80 Hz at various altitude variations. Interval of the first minute, vector velocity shows the flow around the speaker membrane at every height variation of synthetic jets. This is because at 60 seconds, the membrane undergoes a suction phase for a variety of altitude variations. Whereas the
blowing phase was recorded to occur at 160 seconds with vector velocity flow occurring around the orifice, the membrane reaching the heat source at various height variations. The value for the largest vector velocity for triangle waves with a frequency of 80 Hz is indicated by the number $9.48 \times 10^0 \, \text{m/s}$ at 360 seconds which is seen from the end of the orifice when it will do the suction phase again after a while before completing the exhaust phase at the heat source with a height 10 cm. The flow of air exhaled from the orifice to heat sources with a variety of variations in altitude is then released into the environment which is above the source of heat with various variations of altitude. So that the velocity vector created is still formed until it is released into the environment after pounding a heat source with various variations in altitude.

The red color on the legend and the profile shape during the simulation shows the greatest value that occurs in synthetic jet simulations with various variations in altitude. While the dark blue color indicates the lowest value that occurs when synthetic jet simulation with heat sources at various altitude variations is done.

Table 4. Turbulence-Intensity with various height variations.

| Height (cm) | Turbulence-Intensity |
|-------------|----------------------|
| 2           |                       |
| 4           |                       |
| 6           |                       |
| 8           |                       |
| 10          |                       |
| 12          |                       |
| 14          |                       |
| 16          |                       |
| 18          |                       |
| 20          |                       |

Table 4. shows the shape of the turbulence-intensity profile created on synthetic jets using triangle waves with a frequency of 80 Hz at various altitude variations. Interval of the first minute, turbulence-intensity shows the flow around the speaker membrane at any height variation of synthetic jets. This is because at 60 seconds, the membrane undergoes a suction phase for a variety of altitude variations. Whereas the blowing phase was recorded to occur at 160 seconds with turbulence-intensity flow occurring around the orifice, the membrane reaching the heat source at various height variations. The highest value for turbulence-intensity for triangle waves with a frequency of 80 Hz is indicated by the number $2.10 \times 10^0$ at 160 seconds which is seen from the end of the orifice when going to discharge phase at a heat source with a height of 2 cm where after the flow of air touches the heat source then air up to the environment so that the highest turbulence-intensity is formed. The flow of air exhaled from the orifice to heat sources with a variety of variations in altitude is then released into the environment which is above the source of heat with various variations of altitude. So that the turbulence-intensity flow created is still formed until it is released into the environment after pounding a heat source with various variations in altitude.

The red color on the legend and the profile shape during the simulation shows the greatest value that occurs in synthetic jet simulations with various variations in altitude. While the dark blue color indicates the lowest value that occurs when synthetic jet simulation with heat sources at various altitude variations is done.
5. Conclusion
Research on synthetic jets with variations in altitude of synthetic jets to heat sources has produced various and interesting cooling effects. From computer analysis through software and direct data retrieval has been carried out on a synthetic jet with a new design and different from previous studies. Based on this, the following conclusions can be determined:

1. The characteristics of each wave are different, so I use triangle/triangular waves. Triangle waves show a decrease in temperature of the heat source for 3600 seconds well enough to reach a temperature of 28.1.
2. The frequency used is 80 Hz. The selection of 80 Hz was chosen because it is the optimum frequency based on several previous studies. Based on research with a frequency of 80 Hz, the cooling process runs not too long and not too fast.
3. The effect of altitude on the cooling process occurs varies at each height. A height of 8 cm results in a fairly rapid cooling process compared to other heights. But with a height of 2 cm from the heat source, it produces the coldest final temperature at 28.1.
4. The forms of profile contour vorticity, vector velocity, and turbulence intensity produced by synthetic jets with variations in height have almost the same shape. There are 3 phases that can be identified with the help of fluent software, namely the exhaust phase, the suction phase, and the exhaust phase. For the amount of flow values can be seen in the legend to the left of each profile picture. Where for large values are depicted in red, and small values are indicated in blue.

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