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Heat Transfer Characteristic of Vertical Cooling Using Synthetic Jet

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ABSTRACT – Advancements in technology have resulted in a rise in heat flow within electrical devices. Electronic devices that overheat can break down and experience thermal failure. One cooling method that may be able to prevent electronic overheating is a synthetic jet.This study examined the cooling efficiency and optimal performance characteristics of a synthetic jet cooling device using a vertical cooling approach. The experiment utilized a synthetic jet with varying nozzle sizes (diameters of 2 mm, 4 mm, 6 mm, 8 mm, and 10 mm), volume cavities (depths of 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm), and distances between the heater and synthetic jet (distances of 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, and 70 mm). The synthetic jet was held at a consistent frequency of 500 Hz, while the heater, which acted as the processor for the electrical device, was set to a constant temperature of 70 °C. The experimental results indicate that a nozzle diameter of 2 mm yields the best cooling effects compared to other nozzle diameters tested. The optimum distance found from the experiment is 30 mm. The lowest average surface temperature is 40.53°C with a heat transfer coefficient 98.99W/m².°K with a Nusselt number of 7.56.

KEYWORDS: electronic cooling heat, dissipate zero net mass flux, resonance frequency, synthetic jet, vertical cooling, synthetic vertical cooling, synthetic heat transfer characteristics

1.0 INTRODUCTION

With the continuous progress of technology and the increasing compactness and power of devices, the management of heat dissipation becomes more and more crucial. Excessive heat can cause electronic devices to experience thermal failure and ultimately will break down. The development of newer cooling systems that can either replace or improve existing ones is being driven by the growing cooling demands of modern electronic components [1]. One way to achieve this is by using synthetic jets, which have a higher level of turbulence by design, which leads to better mixing [1]. In a recent study, it was suggested that the type of equipment used to move the fluid, like a loudspeaker or a piezoelectric transducer, is more important than the appearance of cavity fins [2]. When compared to the more important device types, fins don't have much of an effect on how well Synthetic Jet Actuators (SJA) work [2]. In a recent study, the use of a thermoacoustic engine to convert heat into acoustic oscillations was employed to investigate formation of synthetic jets in an external quiescent environment for cooling applications. The researchers discovered that the engine can drive synthetic jets through 10 orifices at a temperature difference of less than 150 °C, with the working medium of CO_2 at ambient pressure [3]. Arumuru V. et al conducted a comparison between phase change material (PCM) with a DC fan and PCM equipped with a synthetic jet, and the researchers discovered that the synthetic jet, equipped with many orifices, outperformed the Direct Current (DC) fan when both were operated at the same level of electrical power input [4].

The diaphragm of a synthetic jet operates by drawing in fluid and expelling it through an opening. The volume of fluid entering and exiting the synthetic jet cavity is dependent on its size. Thus, the performance of a synthetic jet is dependent on the volume of the cavity [5].

A recent study investigating thermal, flow, and acoustic characteristics in a loudspeaker-driven synthetic jet geometry revealed that the resonance frequency exhibits the most effective cooling performance. However, the number of orifices also influences the performance. [6]. In their work on twin synthetic jets actuators, Kang Ying et al. found that increasing the diaphragm frequency from 15 Hz to 80 Hz only slightly enhances heat transmission and has a negligible impact on pressure drop[7].

In another study, M. Chaudhari et al. found that synthetic jet applications can use circular, square, and rectangular nozzles. Rectangular orifice nozzles have a higher Nusselt number than circular and square ones for nozzle but limited to the lengths below 5 mm. However, the square orifice nozzle outperforms other designs at 5–10 mm distances. The Nusselt number for circular and rectangular orifice nozzles is similar from 5 to 10 mm. Narrow slit orifices produce the lowest average Nusselt numbers. [8]. However, in a study done by Paweł Gil, he concluded that “if the orifice cross section area in the case of single and multiple orifice synthetic jet is similar and real power deliver to the Synthetic Jet Actuator(SJA) is maintained at the same level resulting equivalent Reynolds number and equivalent dimensionless stroke length achieved similar value and the impinging jet equivalent Nusselt number also achieved comparable value and distribution”[9].

X.M. Tan et al. conducted a comparative analysis of nozzle shapes and determined that the round-hole orifice nozzle outperforms other orifices in terms of achieving stronger overall heat transfer [10]. Another recent study has compared the frequencies of synthetic jets ranging from 300 Hz to 700 Hz. It is observed that with a heater-synthetic jet distance of 50mm, it was determined that a frequency of 500 Hz resulted the most effective cooling effects [11]. In a comparative investigation between a single orifice and several orifices with the same exit area, researchers found that using multiple orifices at lower H/D values resulted in higher heat transfer performance [12]. In another recent study, researchers examined the impact of focusing jets from a synthetic jet array (SJ array) on improving heat transfer from a heated plate by investigating jet impingement. The study found that a significant decrease in vortex coherence leads to ineffective heat transfer in the far field [13].

A study conducted using ANSYS FLUENT software simulated a synthetic jet and determined that the highest speed was achieved at a driving frequency of 500 Hz. This finding is consistent with the observation that the resonance frequency of 500 Hz exhibited the greatest amplitude and sweep volume. Additionally, a big swirl was seen during the ejection phase at 500 Hz, which caused the biggest drop in temperature and a higher heat transfer coefficient (h) than the non-resonance frequency. The large vortex formation, fluid velocity, and amplitude of the synthetic jet working at the resonance frequency were all directly related to the heat transfer coefficients [14]. One of position can be place vertically for cooling which may have different effect from other position. It is found that an orifice size of 60° performs slightly better than 30° orifice and 40 percent better than 10° orifice at the same actuator jet outer diameter [15]

One potential configuration for synthetic jet cooling involves placing it vertically, which may result in distinct effects compared to other positions. The parameters used for synthetic jet cooling may differ from those used in other cooling devices, and they also have distinct optimum parameters that have been determined in this study.

2.0 METHODOLOGY

2.1 Experiment configurations

The synthetic jets (Figure 1) will generate vibration and induce bending in the diaphragm of the jet. The oscillation of the synthetic jet generates airflow that produces a cooling effect on the heater.

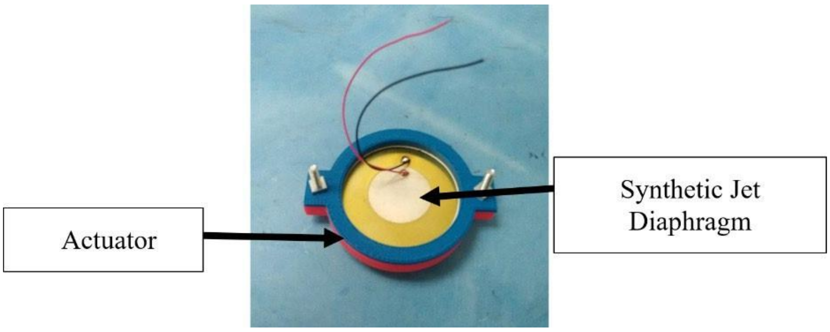

Figure 1: The synthetic jet diaphragm with it actuator

Synthetic jet actuators were utilized to integrate a synthetic jet diaphragm within its structure. The device is equipped with a nozzle that can be adjusted in size and has the ability to hold varying volumes of liquid. The nozzle size varies between 2 mm and 10 mm, while the volume cavity depth spans from 1 mm to 5 mm. There is a total of 25 synthetic jet actuators, each characterized by a distinct combination of nozzle size and volume cavity. Figure 2 exhibits an assortment of synthetic jet actuators.

Figure 2: One of set synthetic jet actuator with different nozzle size and volume cavity

The equipment utilized in the experiment is depicted in Figure 3. The diagram illustrates the general configuration of a synthetic jet generator and the location of the synthetic jet. The experiment was conducted in the vertical cooling position, as depicted in Figure 4. The experimental parameters include the distance between the synthetic jet and the heater, the dimensions of the nozzle, and the volume of the nozzle cavity. Table 1 displays the inventory of equipment utilized in this experiment.

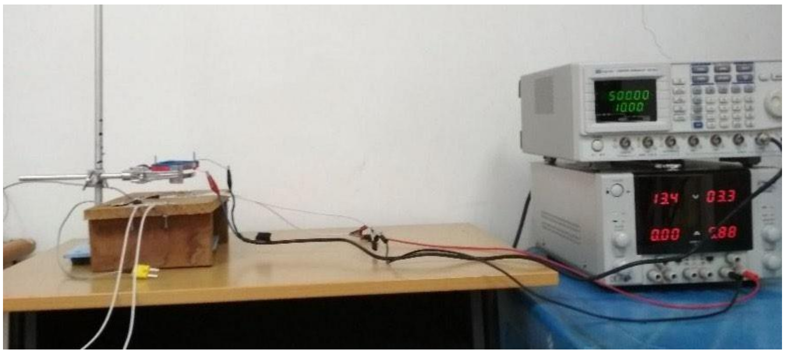

Figure 3: The overall set up of synthetic jet experiment.

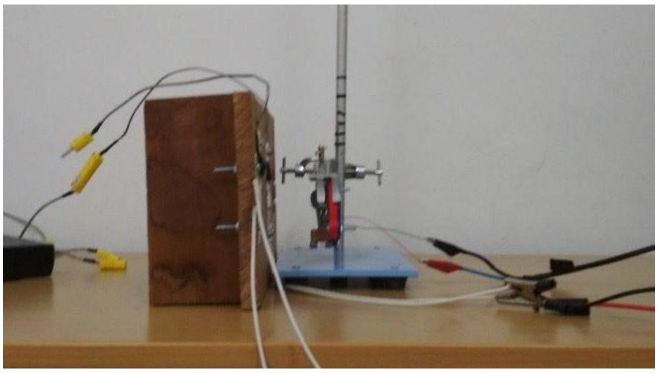

Figure 4: The position of vertical cooling experiment

Table 1: List of equipment and its configurations

Equipment	Functions	Settings
DC Power Supply	Supply electrical power to instruments	Voltage: 6.8 V Current: 2.1 A
Portable Data Acquisition Module	Measure the temperature of ambient and the heater.	
Thermocouple Cable (Type K)	Use to measure the heater's temperature and the ambient temperature	The ambient temperature is measured at channel 0 of the Data Acquisition Module while the heater temperature is measured at channel 2.
Heater 90 V :90W	To generate heat capable of consuming 90 volts and 90 watts of energy when a current of 1 amps flows through it.	Adjust the voltage and current values until the heater temperature reaches 70ºC.
Cable Clip	To connect the circuit between DC Power Supply to the heater	
Function Generator:	Used to generate the frequency signal to oscillate the diaphragm of synthetic jet.	After the heated surface's temperature reaches 343.15 K, generator was on at frequency of 500 Hz and voltage 10 V. After 15 minutes, the temperature must remain constant.

Oscilloscope	To observe the constantly varying signal voltages usually as a two- dimensional plot.	
Retort Stand and Clamp	Used to adjust the distance between the nozzle jet to the heated surface temperature.	
Synthetic Jet Actuator	Consist of cavity volume, piezoelectric diaphragm and orifice that use to ejection and suction heat from the heater	Connect the piezoelectric diaphragm to the function generator in order for the diaphragm to oscillate when the heater temperature reaches 343.15 K
Hot Wire Anemometer	Used to collect data for air velocity of synthetic jet actuator.	Connect the hot wire to the DAQ and ensure that the initial velocity value is 0 m/s. Wait 900 seconds before gathering air velocity data.

The experiment commenced by activating the power source, which then caused the heater to elevate the temperature. The temperature changes can be observed on a computer monitor using the Data Logger Application, which is connected to the Data Acquisition Module (DAM). The voltage and current will be adjusted to 3.5 V and 0.85 A, respectively, in order to raise and maintain the temperature at 70 °C. The heater will remain operational for a period of 15 minutes to ensure a consistent temperature.

Next, the generator was activated with a frequency of 500 Hz and a voltage of 10 V. Experiment was allowed to sit for 15 minutes before capturing data, with a wind shield in place. The experiment has been replicated with varying distances, nozzle sizes, and volume cavities. Each experiment must wait for the heater to attain a steady temperature of 70 °C, while maintaining a voltage of 90 V and a current of 1 A.

The data obtained from the experimental run are represented in heat transfer coefficient, h and Nusselt number, Nu as shown below.
The formula used to calculate heat transfer coefficient, h:

$$h = \frac{q_{conv}}{T_s - T_\infty} \quad (1)$$

Where, T_∞= Temperature ambient, (°C) which is fixed at 25°C in this study

The Nusselt number is calculated by using equation below.

$$Nu = hd/k \quad (2)$$

Where,

h = heat transfer coefficient

d = Diameter nozzle (m)

k = Air thermal conductivity (W/mK). It is assumed that the value is set at 0.0262 W/mK in this investigation.

3.0 RESULT AND DISCUSSION

3.1 Experimental Result

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The data obtained from the experiment by conducting 5 size of nozzles (2mm, 4mm, 6mm, 8mm, and 10mm), 5 different depth of volume cavities (1mm, 2mm, 3mm, 4mm and 5mm) and 7 distance values (10mm, 20mm, 30mm, 40 mm, 50 mm, 60mm and 70mm) is tabulated in Table 2.It displays the Nusselt number, which is determined by solving equation (2). This value provides insight into the relationship between heat transfer rates in convection and the resulting heat transfer rates in conduction.

Table 2: The Nusselt numbers from experimental results.

Diameter Nozzle (mm)	Depth of Volume Cavity (mm)	Distance (mm) Nusselt Number						
		10	20	30	40	50	60	70
2	1	5.31	6.33	7.56	6.29	5.68	5.08	5.02
	2	4.55	5.73	6.53	6.07	5.58	4.73	4.63
	3	3.94	5.17	6.14	5.66	4.73	4.45	4.12
	4	3.75	4.80	5.10	4.88	4.29	3.91	3.67
	5	3.56	3.92	4.74	4.14	3.97	3.51	3.12
4	1	8.49	13.01	13.83	13.38	12.65	12.62	10.30
	2	7.97	11.74	13.42	11.29	9.98	9.57	8.32
	3	7.74	10.77	12.25	10.10	9.37	7.35	7.08
	4	7.53	9.10	9.89	10.07	8.19	6.72	6.63
	5	6.55	7.37	8.57	7.56	6.77	5.86	5.67
6	1	10.59	12.08	8.72	7.80	7.71	7.78	7.71
	2	9.53	10.72	8.44	7.76	7.67	7.78	7.69
	3	8.87	7.98	7.76	7.72	7.70	7.82	7.72
	4	7.92	8.05	7.78	7.68	7.66	7.78	7.68
	5	7.98	7.63	7.85	7.75	7.73	7.77	7.68
8	1	11.72	13.00	10.59	10.38	10.30	10.31	10.37
	2	11.34	12.21	10.63	10.40	10.28	10.25	10.45
	3	11.14	11.84	10.60	10.45	10.32	10.30	10.35
	4	10.65	11.58	10.58	10.42	10.30	10.27	10.35
	5	10.49	11.23	10.51	10.37	10.25	10.22	10.30
10	1	15.04	14.66	12.95	12.80	12.77	12.96	12.80
	2	14.61	13.68	13.08	12.93	12.90	13.09	12.94
	3	14.10	13.49	13.05	12.90	12.87	13.07	12.89
	4	13.49	13.07	13.02	12.88	12.85	13.04	12.88
	5	13.07	12.95	13.00	12.85	12.82	13.01	12.85

3.2 Effect of nozzle size on Nusselt number

Figure 5 illustrates the correlation between the Nusselt number and the diameter of a 2mm nozzle. The Nusselt numbers were computed for each volume cavity at different depths using equation (2). The Nusselt number is the lowest at a distance of 70mm with a cavity depth of 5mm, measuring 3.12. Conversely, the highest Nusselt number is seen at a distance of 30mm with a cavity depth of 1mm, measuring 7.56. Additionally, it demonstrates a declining trend in the Nusselt number as the depth of the volume cavity increases. The chart displays an initial increase from a distance of 10mm to 30mm, followed by a subsequent decrease in volume cavity depth as the distance increases from 30mm to 70mm.

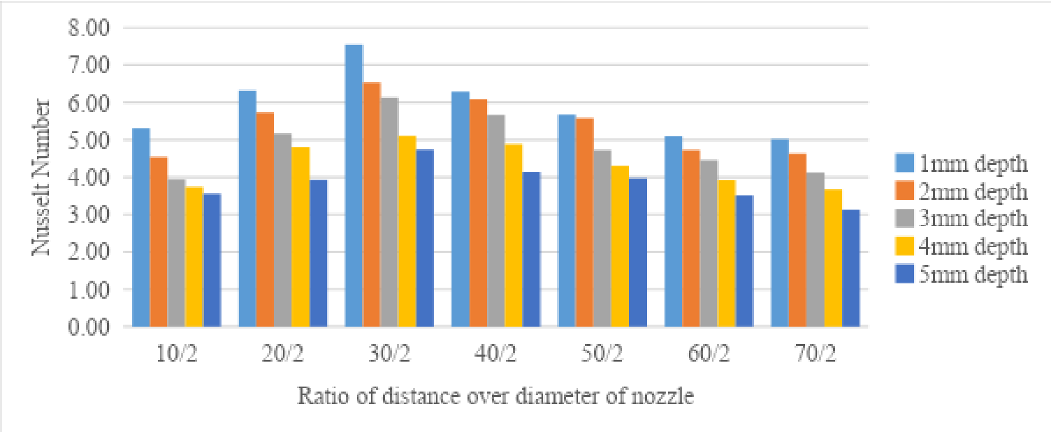

Figure 5: The Nusselt number with diameter nozzle 2mm

Figure 6 displays the Nusselt number values corresponding to a nozzle diameter of 4mm. The Nusselt number was determined using equation (2) for each volumetric cavity at different depths. The Nusselt number (Nu) of 5.67 was observed at a distance of 70mm from the 4mm nozzle, as displayed in Figure 6. This reading was taken within a cavity with a depth volume of 5mm. At a distance of 30mm, the greatest value is achieved for a volume cavity depth of 1mm, with a corresponding value of Nu=13.83. Additionally, it has been shown that the Nusselt number decreases as the depth of the volume cavity increases. According to the chart, the Nusselt number exhibits an increasing trend as the distance increases. However, at a distance of 40mm, the performance starts to decline, resulting in a lower Nusselt number.

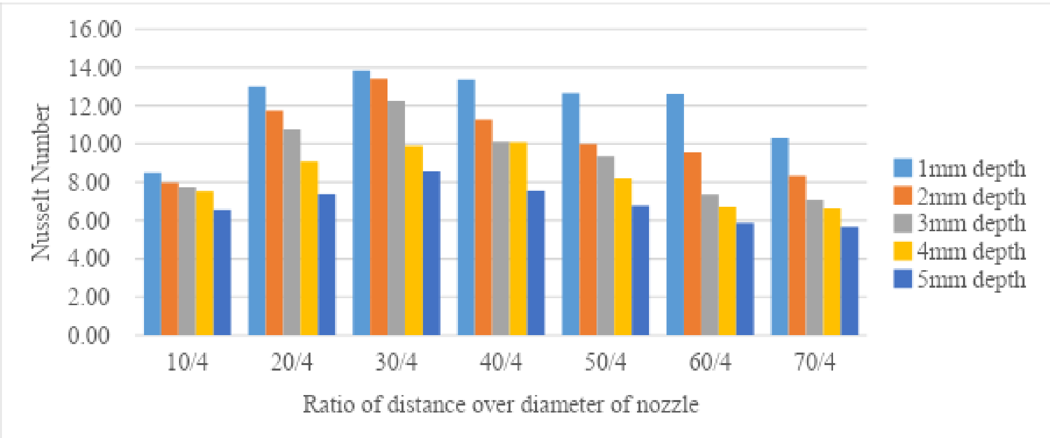

Figure 6 : The Nusselt number with diameter nozzle 4mm

The Nusselt number reaches its maximum value of 12.08 at a distance of 20mm in the configuration with a 6mm nozzle and a cavity depth of 1mm (Figure 7). The Nusselt number remains approximately constant at a value of 7 for every depth of the volume cavity ranging from 40mm to 70mm.

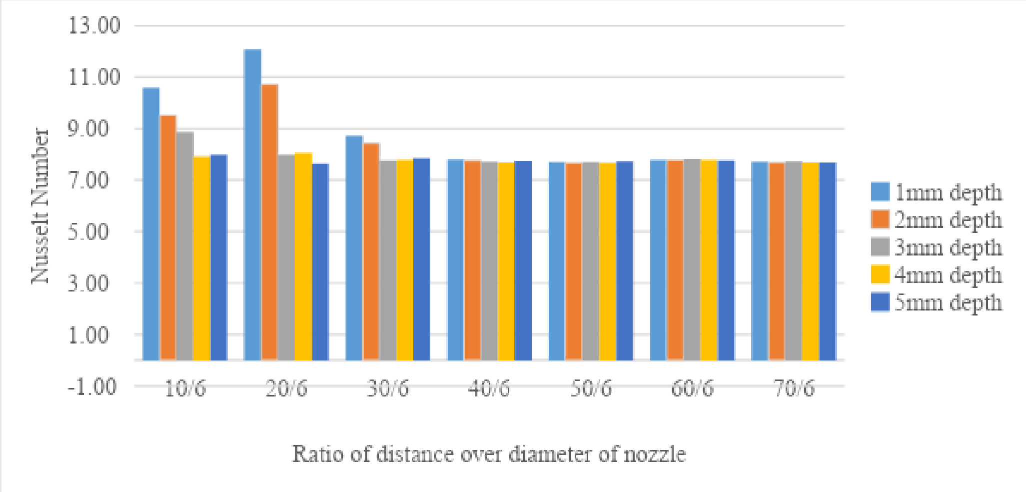

Figure 7: The Nusselt number with diameter nozzle 6mm

In the experiment using an 8mm nozzle, the Nusselt number achieves its peak value of 12.21 at a distance of 20mm from the nozzle (Figure 8). This occurs within a cavity that has a volume depth of 1mm. The Nusselt number has a consistent value of approximately 10 over the various depths of the volume cavity, between 30mm to 70mm.

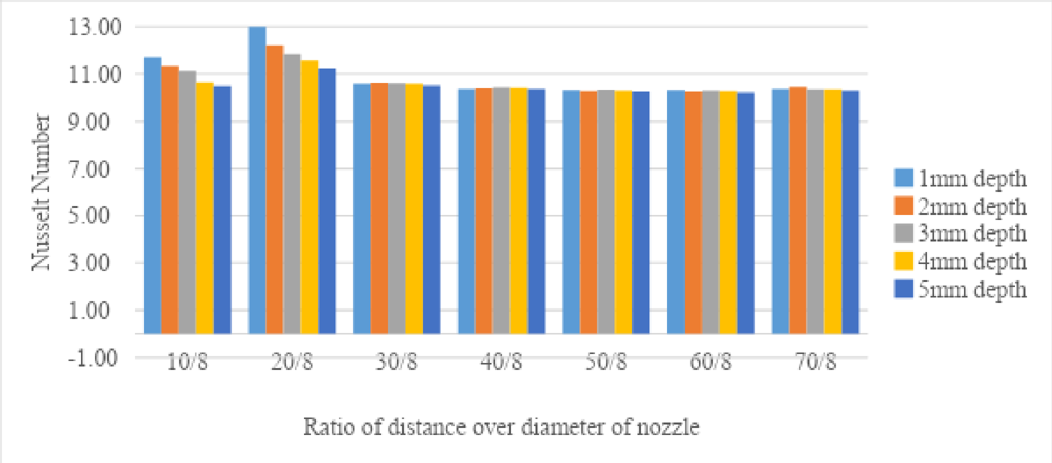

Figure 8: The Nusselt number with diameter nozzle 8mm

Figure 9 shows that the Nusselt number is maximum at a distance of 10mm from the nozzle with a diameter of 10mm. The depth of the cavity is 1mm, and at this depth, the Nusselt number is measured to be 15.04. The Nusselt number remains relatively consistent at around 13 within the range of 30mm to 70mm for each volume cavity depth.

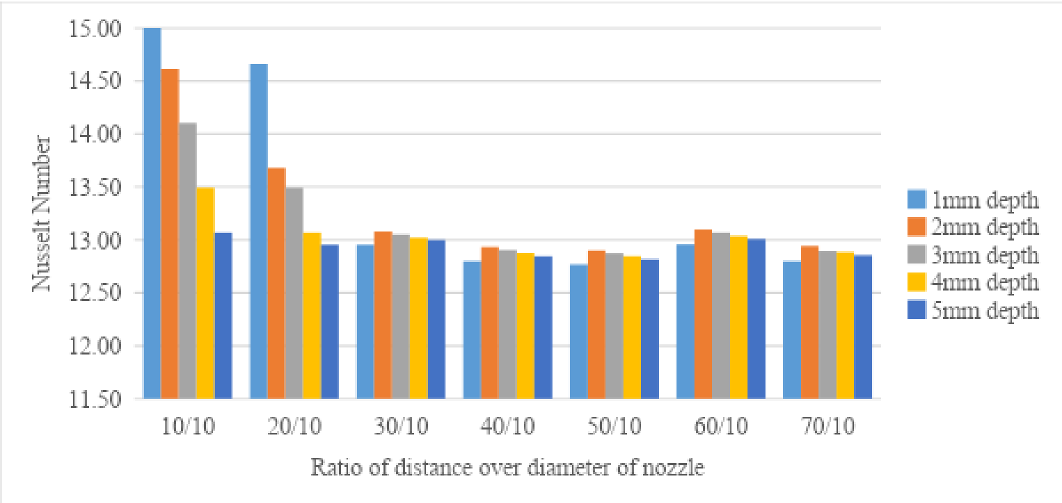

Figure 9: The Nusselt number with diameter nozzle 10mm

Based on the analysis of each nozzle, the average temperature pattern is similar to the findings of study [10], where the lowest average temperature is observed at a distance of approximately 30mm. The performance of the setup declines as the distance exceeds 30mm, as the vortex begins to dissipate [5]. By increasing the depth of the volume cavity, the average temperature for each nozzle will increase. The Nusselt number and heat transfer coefficient exhibits a similar trend. The analysis revealed that the minimum temperature was seen at a depth of 1mm within the volume cavity.

4.3 Depth of Volume Cavity effects

Figure 10 illustrates the relationship between the Nusselt number and the depth of the volume cavity, which is 1mm. The Nusselt number reaches its maximum value of 15.04 at a distance of 10mm with 10mm nozzle. Figure 11 demonstrates that, similar to the picture in Figure 10, the Nusselt number reaches its maximum value of 14.61 at a distance of 10mm with a nozzle diameter of 10mm.

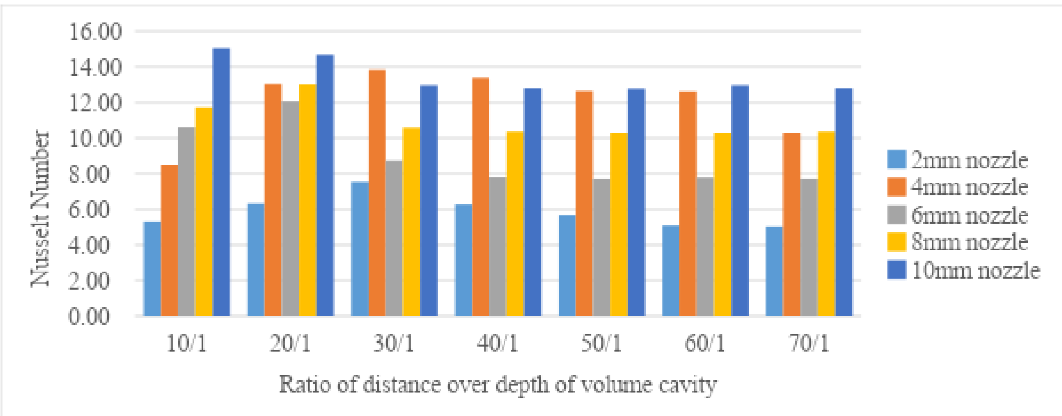

Figure 10: The Nusselt number with depth of volume cavity 1mm

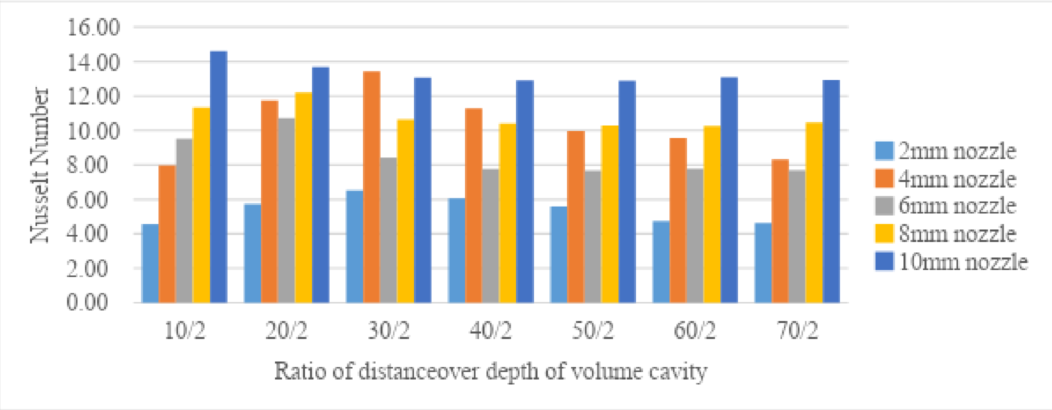

Figure 11: The Nusselt number with depth of volume cavity 2mm

Figure 12, Figure 13, and Figure 14 depict the Nusselt number trend at different depths of the volume cavity, specifically at 3mm, 4mm, and 5mm, respectively. The arrangement with a 10mm nozzle diameter exhibits the greatest Nusselt number among all volume cavity configurations. The figures ranked highest are 14.10, 13.49, and 13.07, respectively.

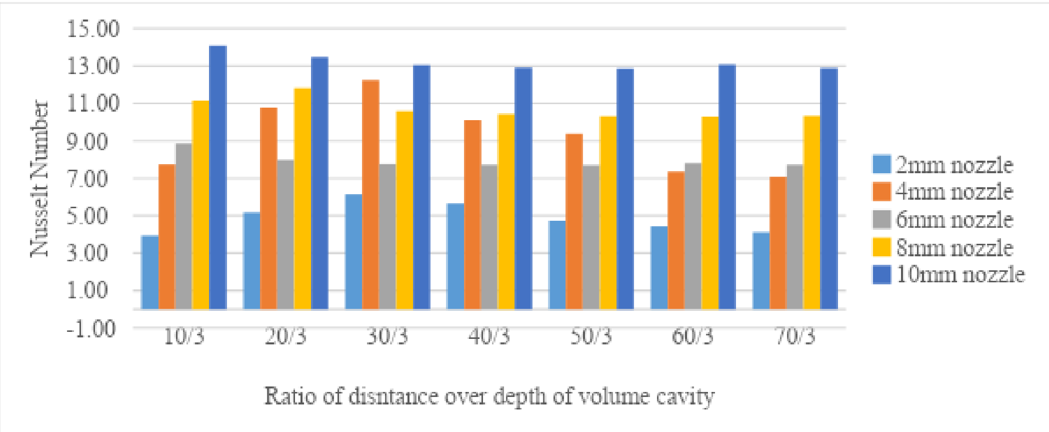

Figure 12: The Nusselt number with depth of volume cavity 3mm

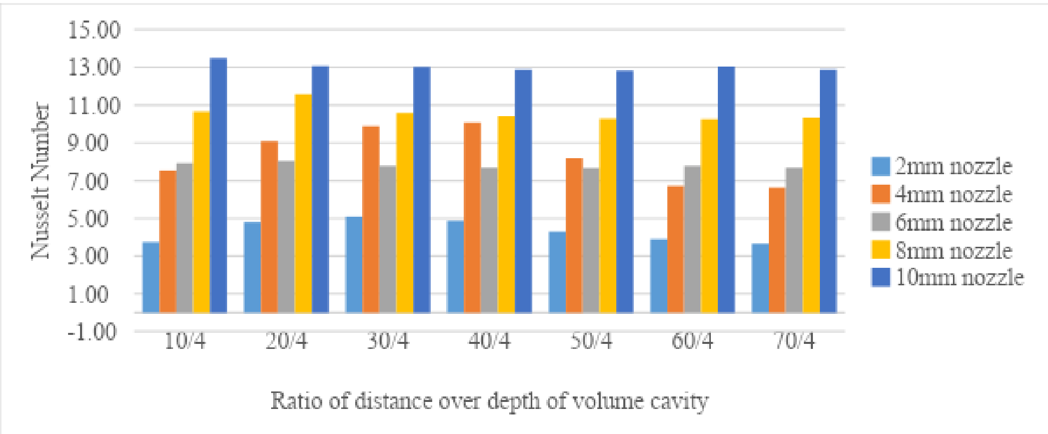

Figure 13: The Nusselt number with depth of volume cavity 4mm

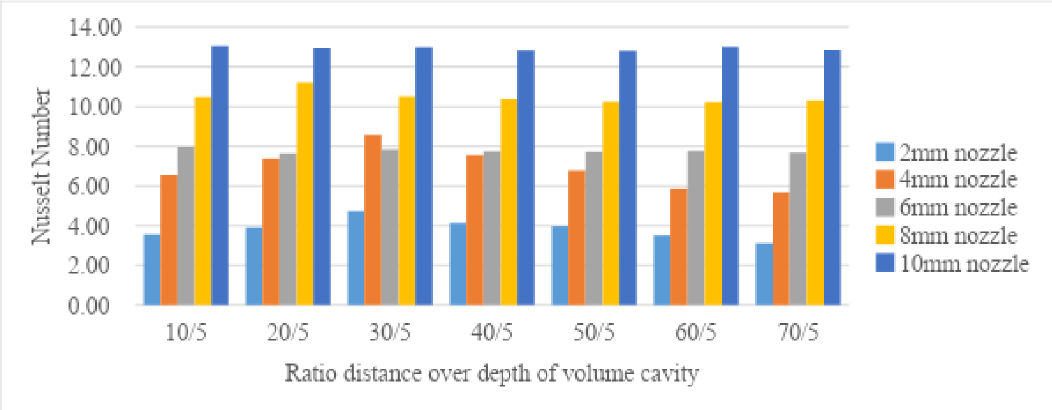

Figure 14: The Nusselt number with depth of volume cavity 5mm

The maximum Nusselt number is achieved while using a 10mm nozzle diameter and a 10mm spacing in all variations of volume cavity configurations. The decreasing performance appears to be noticeable at a distance of 40mm and beyond, particularly when using nozzle diameters of 2mm and 4mm.

4.4 Effects of Distance to Heat Surface

In Figure 15, the Nusselt number reaches its maximum value of 15.04 at a distance of 10mm, at a depth of 1mm within the volume cavity, with a nozzle diameter of 10mm.

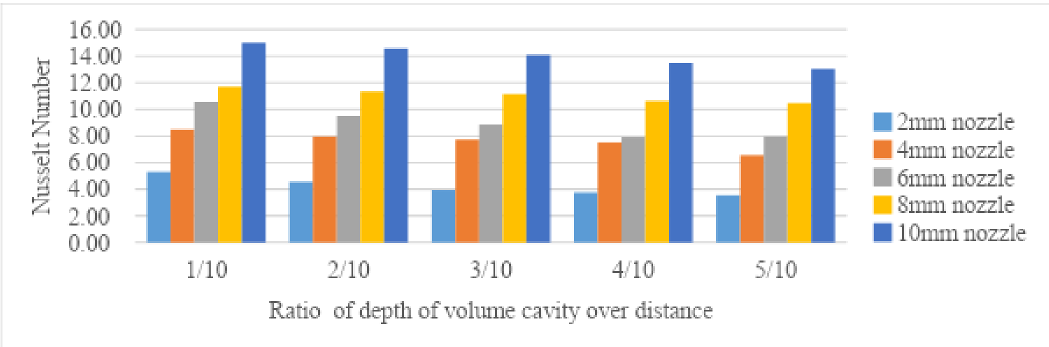

Figure 15: The Nusselt number at distance 10mm

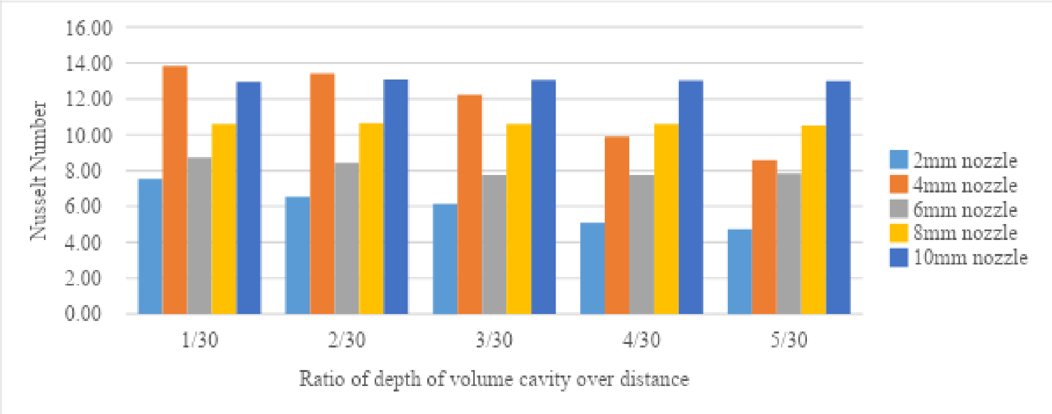

Figure 15: The Nusselt number at distance 20mm

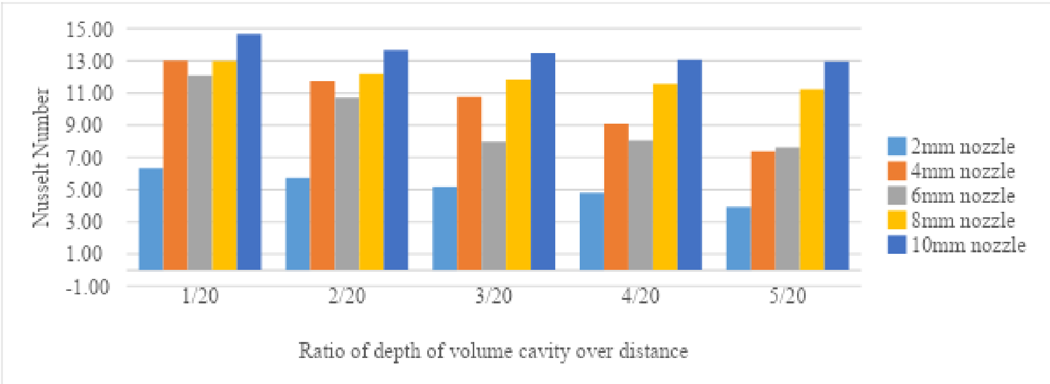

Figure 16: The Nusselt number at distance 30mm

Figure 15 and Figure 16 display the Nusselt number at a distance of 20mm and 30mm, respectively. The Nusselt number at a depth of 1mm in the volume cavity with a diameter nozzle of 10mm is 14.66 for a distance of 20mm. At a distance of 30mm, the configuration with a 4mm nozzle achieved a Nusselt number of 13.83, which is the highest recorded value at distance 40mm. A similar pattern was observed at a distance of 40mm in the arrangement. The maximum Nusselt number was discovered at a depth of 1mm within the volume cavity, with a nozzle diameter of 4mm. This value was measured to be 13.38, as depicted in Figure 17.

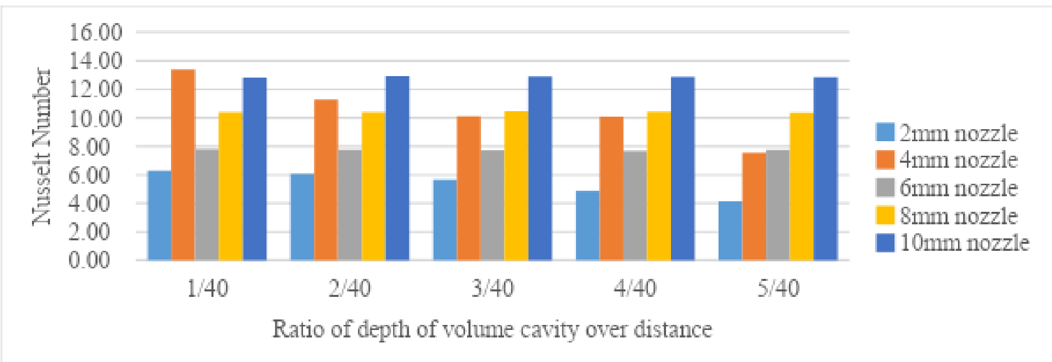

Figure 17: The Nusselt number at distance 40mm

Figure 18 displays the Nusselt number data at a distance of 50mm. The Nusselt number reaches its maximum value of 12.77 at a depth of 1mm within the volume cavity, with a nozzle diameter of 10mm. Figure 19 displays the Nusselt number data at a distance of 60mm. The Nusselt number reaches its maximum value of 12.96 at a depth of 1mm within the volume cavity, using a nozzle with a diameter of 10mm. The data in Figure 20 represents the Nusselt number at a distance of 70mm. The Nusselt number reaches its maximum value of 12.94 at a depth of 2mm in the volume cavity, with a nozzle diameter of 10mm.

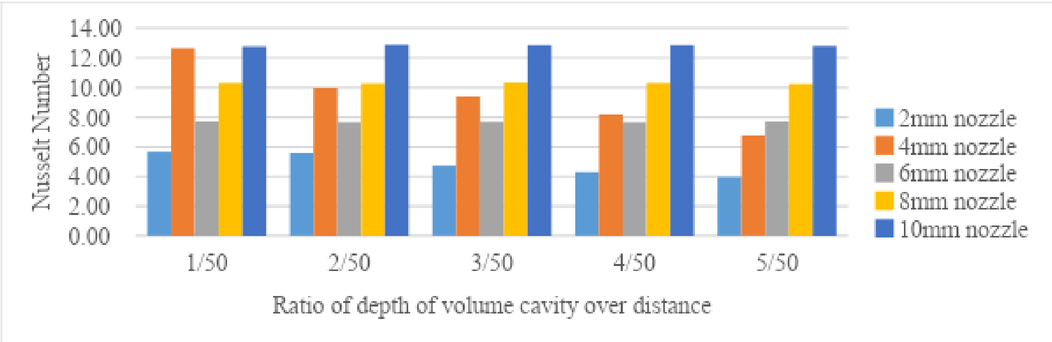

Figure 18: The Nusselt number at distance 50mm

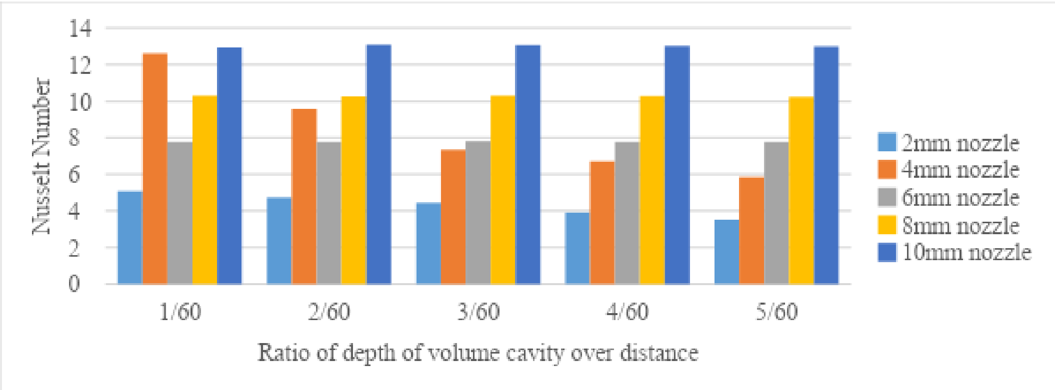

Figure 19: The Nusselt number at distance 60mm

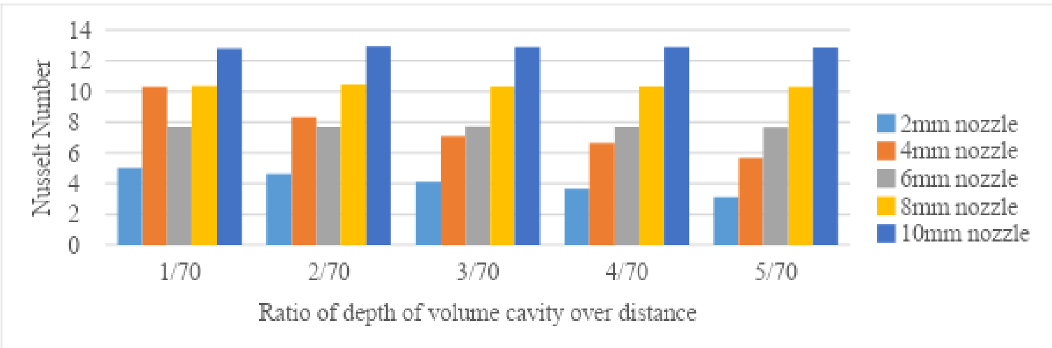

Figure 20: The Nusselt number at distance 70mm

Upon investigation, it is evident that the changes in distance are only minor in comparison to the more significant variations observed in the volume depth and volume depth. The pattern observed in the early discussion shows a small similarity, where the average temperature increases as the depth of the volume cavity increases, but the heat transfer coefficient decreases with increasing depth of the volume cavity. With the exception of the Nusselt number graph, when the diameter of the nozzle is increased, the Nusselt number exhibits a non-linear growing trend. This is due to each nozzle has a different diameter, resulting in varying values of the Nusselt number. However, the pattern remains the same throughout the distance, with the highest value observed at 30mm. The tiny error in performance of a 4mm diameter nozzle may be caused by disturbances in the airflow near the heater.

4.0 CONCLUSION

Based on the analysis, the optimal performance of the synthetic jet for vertical cooling occurs at a distance of 30mm. The optimal volume cavity depth is 1mm, and the nozzle diameter should be 2mm. This particular arrangement yields the maximum heat transfer coefficient, which amounts to 98.99 W/m^2. °K. A spacing of 30mm consistently produces the most effective cooling in all configurations including varying nozzle diameters and cavity depths. The performance of synthetic jet decreases as the depth of the volume cavity increases. It is important to note that the performance will decrease even more beyond the distance of 30mm.

For further additional research, attention might be directed into studying the variability in the shape of the volume cavity, rather than limiting it to a cylinder as done in this study. A cone is one possible option for the shape of a volume cavity. This can enhance the creation of a vortex generated by a synthetic jet. The synthetic jet is now positioned at a 90-degree angle to the heater, resulting in vertical cooling. Hence, future research should prioritize investigating the impact of varying the angle between the synthetic jet and heater surface to get further insights into the influence of angle on synthetic jet performance.

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REFERENCES

[1] C. Y. Y. Lee, M. L. Woyciekoski, and J. B. Copetti, 2016. Experimental study of synthetic jets with rectangular orifice for electronic cooling, *Exp Therm Fluid Sci*, 78:242–248, doi: 10.1016/J.EXPTHERMFLUSCI.2016.06.007.

[2] E. Smyk, P. Gil, R. Gałek, and Ł. Przeszłowski,2020.Acoustic and Flow Aspects of Novel Synthetic Jet Actuator, *Actuators*, vol. 9(4):100, doi: 10.3390/act9040100.

[3] A. Hamood, M. Ja'fari, and A. J. Jaworski, 2023.Synthetic jet flow driven by a standing-wave thermoacoustic heat engine, *Thermal Science and Engineering Progress*, 39:101725, doi: 10.1016/j.tsep.2023.101725.

[4] V. Arumuru, K. Rajput, R. Nandan, P. Rath, and M. Das, 2023. A novel synthetic jet based heat sink with PCM filled cylindrical fins for efficient electronic cooling, *J Energy Storage*, 58:106376, doi: 10.1016/j.est.2022.106376.

[5] O. Ghaffari, S. A. Solovitz, and M. Arik. "An investigation into flow and heat transfer for a slot impinging synthetic jet," *Int J Heat Mass Transf*, 100:634–645, doi: 10.1016/J.IJHEATMASSTRANSFER.2016.04.115 ,2016.

[6] P. Gil, E. Smyk, R. Gałek, and Ł. Przeszłowski."Thermal, flow and acoustic characteristics of the heat sink integrated inside the synthetic jet actuator cavity," *International Journal of Thermal Sciences*, 170:107171, doi: 10.1016/J.IJTHERMALSCI.2021.107171 , 2021.

[7] Ying Kang, Zhen-bing Luo, Xiong Deng, Pan Cheng, Can Peng, Wei He, Zhi-xun Xia. "Numerical study of a liquid cooling device based on dual synthetic jets actuator," *Appl Therm Eng*, 219: 119691, doi: 10.1016/j.applthermaleng.2022.119691 ,2023.

[8] M. Chaudhari, B. Puranik, and A. Agrawal. "Effect of orifice shape in synthetic jet based impingement cooling," *Exp Therm Fluid Sci*, 34(2):246–256, doi: 10.1016/J.EXPTHERMFLUSCI.2009.11.001., 2010.

[9] P. Gil,. "Flow and heat transfer characteristics of single and multiple synthetic jets impingement cooling," *Int J Heat Mass Transf*, 201: 123590, doi: 10.1016/j.ijheatmasstransfer.2022.123590, 2023.

[10] X. M. Tan, J. Z. Zhang, S. Yong, and G. N. Xie. "An experimental investigation on comparison of synthetic and continuous jets impingement heat transfer," *Int J Heat Mass Transf*, 90: 227–238, doi: 10.1016/J.IJHEATMASSTRANSFER.2015.06.065, 2015.

[11] H. Ismail, A. Fadzli, A. F. Zubair, M. F. Abd Manap, H. Yusoff, and S. M. F. Sh Abdul Nasir." Effect of cavity volume on cooling performance of synthetic jet device," *Jurnal Mekanikal*, 142–154, doi: 10.11113/jm.v46.498 ,2023.

[12] E. Ergur and T. Calisir. "Computational study of flow and thermal behavior of a single-cavity and multiple-orifice impinging synthetic jets under low orifice-to-target distances," *Thermal Science and Engineering Progress*, 48:102432, doi: 10.1016/j.tsep.2024.102432 , 2024.

[13] J. Pasa, N. V. Shathrughnu, and V. Arumuru. "Impingement heat transfer enhancement by focusing the jet from synthetic jet array," *International Communications in Heat and Mass Transfer*, 152:107306, doi: 10.1016/j.icheatmasstransfer.2024.107306 , 2024.

[14] S. M. Firdaus, M. Z. Abdullah, M. K. Abdullah, and Z. M. Fairuz. "Heat Transfer Performance of a Synthetic Jet at Various Driving Frequencies and Diaphragm Amplitude," *Arab J Sci Eng*, vol. 44(2):1043–1055, doi: 10.1007/s13369-018-3395-8 , 2019.

[15] O. Işil, B. Yücesan, and M. Arik. "Impact of Orifice Size over Mechanical, Flow and Thermal Performances of Synthetic Jets," *17th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, 164–170. doi: 10.1109/ITHERM.2018.8419619 , 2018.