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A Review of Experimentation of Synthetic Jet Cooling

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ABSTRACT

As the electronic device is becoming more advance, the traditional cooling fan in becoming more constrained to its limited dimensions or space. The compact electronic devices with substantial power requirements and tiny electronic components are prone to overheating. This is because these devices dimensions make heat transmission less efficient, making the overheating more likely. Because of the increasing need for smaller devices, makers of electronic components are being compelled to pack transistors into ever-smaller places. This has led to an increase in the amount of overheating that occurs because thermal flow is being constrained. The current period, with its thin and compact electronics, calls for an improved method of cooling, and the synthetic jet-cooling technique will be the subject of the attention of this particular piece of research. The purpose of this study is to discuss the working principles and numerical technique for the synthetic jet cooling that was used in the earlier investigations which investigate the frequency, the distance between synthetic jet and heater, size of the synthetic jet nozzle and size of the synthetic jet volume. In order to make additional progress in enhancing the advancement of synthetic jet technology, it is vital to reviews relevant past research that falls within the area of the study. In addition, as compared to experimental efforts, the numerical technique may result in cost savings and time savings. The use of numerical simulation is essential for accelerating the improvement of the synthetic jet product since it opens up a large potential in the use of electronic devices.

1. Introduction

In the present moment, the development of electronic devices is moving in the direction of miniaturizing the size of an electric device and high-power density. The issue of heat dissipation has become one of the most significant obstacles to its further development [15,22,37]. On the other hand, the capability of naturally occurring convection to disperse heat is quite restricted. The size of traditional fans to cool is also limited by considerations such as space requirements, noise levels, and reliability [31].

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Other researcher has also stated of the shrinking of electronic components and the rapid development of integrated circuits, thermal management of electronic devices has become an increasingly important challenge for engineers. This is owing to the fact that integrated circuits are becoming more common. It is possible that conventional cooling systems, such as fans and heat sinks of a variety of designs, may not be able to tolerate the large heat fluxes generated by the next generation of electronics. Synthetic jet impingent cooling is a relatively cutting-edge solution to this issue which is overcoming overheating and built size [21].

The dramatic growth in human dependency on electronic devices and components has led to fast developments in tech company. As a consequence of this, the production of high-power, high-density, and high-speed microchips increased at an exponential rate, in accordance with Moore's law. Microchips with a high speed that conform to Moore's law. The faultless operation of these electronic systems may be disrupted by a number of variables including thermal overstressing, humidity, dust, noise, vibration, and so on. These and other problems include: However, out of all of these elements, the temperature of the surrounding environment has the greatest impact on the system's dependability [28].

2. Methodology

Synthetic jet has crept its way into the spotlight of general interest. The synthetic jet actuator is an innovative kind of flow generator that has been the subject of intense research since the 1990s. As a novel form of active flow control technology, it has a compact structure and is simple to integrate. This is in contrast to natural convection, conventional fan cooling, and traditional continuous jet, all of which are also examples of active flow control. The absence of moving components promotes a decrease in noise, a low consumption of energy, the absence of a fluid pipeline, as well as stability, safety, and dependability [4-8,24,46]. In addition, when compared with natural convection and traditional fan cooling, synthetic jets have the potential to dramatically improve heat transfer capacities. A chamber that has an oscillating diaphragm, together with a tiny opening, is often used in the production of synthetic jets. The surrounding fluid is alternately drawn into and then blasted out of the chamber through the opening as a result of the periodic oscillations of the diaphragm that occur at a certain frequency [6,50].

A train of vortices is created by synthetic jet actuators, often known as SJAs. These vortices are made by periodically sucking in and expelling the same volume of fluid via an aperture. This creates a directed flow that has no net mass input and is created from the fluid that is ambient to the opening; hence, it is referred to as a "synthetic" jet. Actuators of this sort have been used, for example, in aviation applications, as well as more recently, in the thermal management of electronic devices, in order to regulate flow separation and noise [15,21].

There are other synthetic jet actuators, which move the fluid with the help of a loudspeaker, piezo-electric transducer, piston, or plasma. The synthetic jet may be used for a variety of purposes, including flow control, propulsion, and the increase of heat transfer [4,5,13,14]. There are four different configurations of the synthetic jet that may be used to improve heat transmission. These configurations are shown diagrammatically in Figure 1.

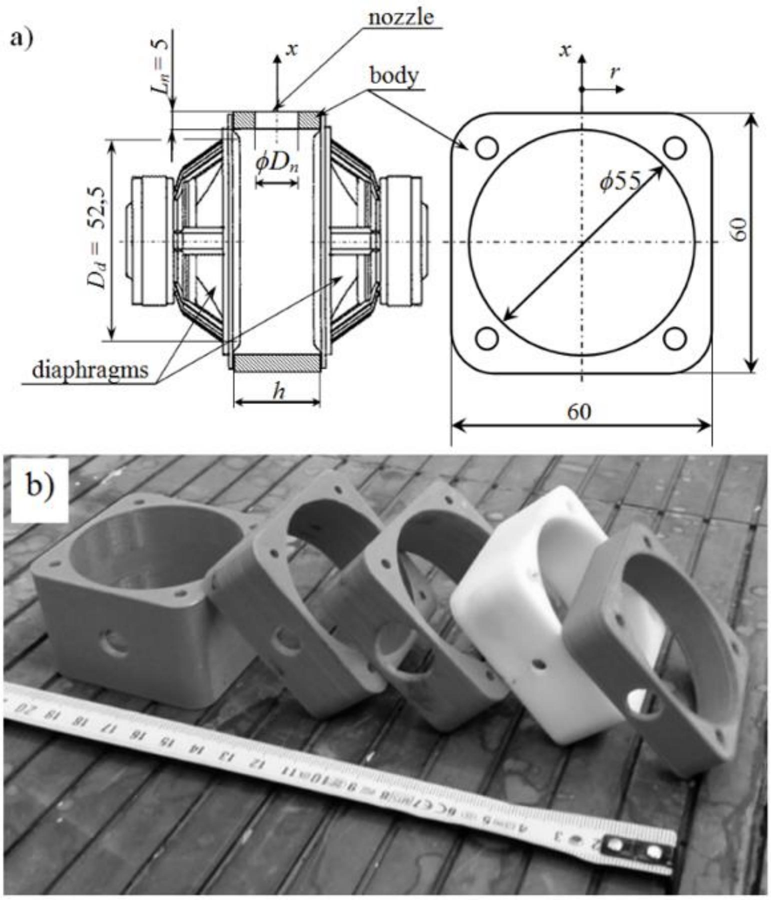

Fig. 1. (a) Schematic of the studied jet actuator; (b) Actuator photo [41]

The amplification of the heat transfer that occurs in laminar channel flow is seen in Figure 1(a). The synthetic jets that hit a flat surface and a heat sink, respectively, are shown in Figure 1(b). It is this setup that the experimental research presented in this study investigates [28, 34-35, 40-42, 47-49].

3. Results

3.1 Frequency

The absolute pressure P that is present inside the cylinder serves as a defining factor for the flow field of the synthetic jet that is created by the piston-cylinder combination. The findings discussed here are derived from several scientific experiments. The temporal history of the pressure within the cylinder is shown in Figure 2 for a variety of orifice sizes as well as multi orifices. The pressure within the cylinder is expressed in absolute terms and then normalized using the pressure of the surrounding atmosphere. It is expressed as the formula Pressure Normalized Rate (PNR) = P/Pa. The value of t is also normalized by the time period of one cycle, denoted by tp, where tp is calculated using the formula $\frac{1}{f}$. When the frequency, f is increased, the PNR will eventually peak at its highest value and drop to its lowest value for each orifice plate. If the plate contains more than one hole and the frequency is increased, the suction and ejection processes that take place over the course of a cycle become asymmetric [9-10]. The influence of the orifice area A has a greater bearing on the maximum PNR when the actuation frequency is increased.

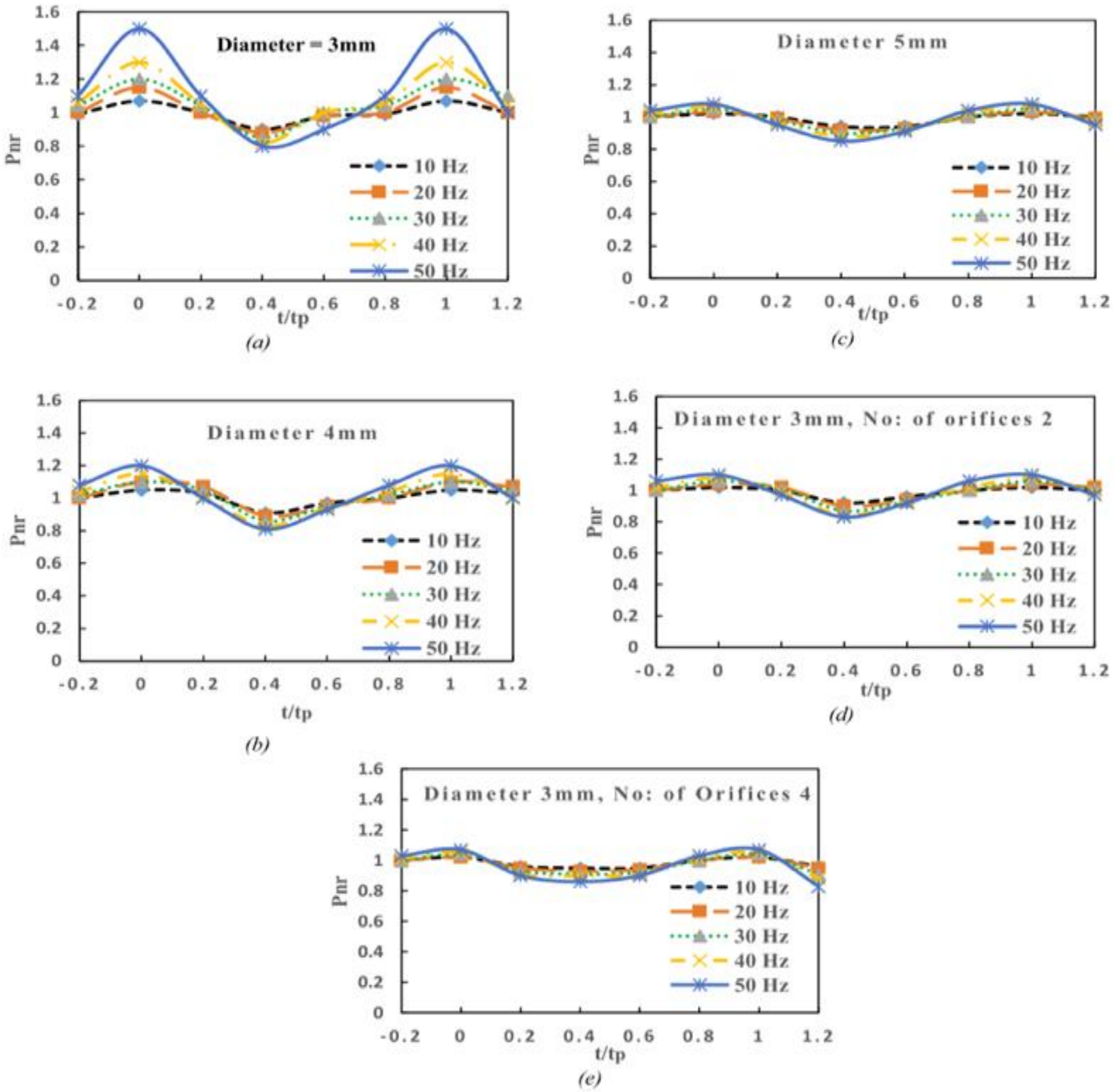

Fig. 2. Time history of cylinder pressure for different frequencies, (a) orifice diameter = 3 mm, (b) orifice diameter = 4 mm, (c) orifice diameter = 5 mm, (d) orifice diameter = 3 mm and number of orifices = 2, (e) orifice diameter = 3 mm and number of orifices = 4. [25]

The maximum normalized pressure (PNR_{max}) and the lowest normalized pressure (PNR_{min}) versus the frequency of a number of different orifices are shown in Figure 3(a) and (b), respectively. In a cycle, the blowing process is represented by PNR_{max}, while the suction operations are represented by PNR_{min}. Both the maximum and minimum PNR values at a given frequency are dependent on the orifice diameter as well as the number of orifices. The total orifice area has a significant impact on both the normalized maximum and the normalized lowest pressure that exist inside of a cylinder. Both the maximum and minimum values of PNR can be attained when the orifice's area is reduced while the actuation frequency is increased. The frequency is varied from 10Hz to 50Hz. As the frequency changes keeping the diameter constant the pressure also changes. It can be seen that as the pressure increases the average Nusselt number also increases. This is due to the fact that as the pressure increases the jet acquires more strength [2,11,12,25].

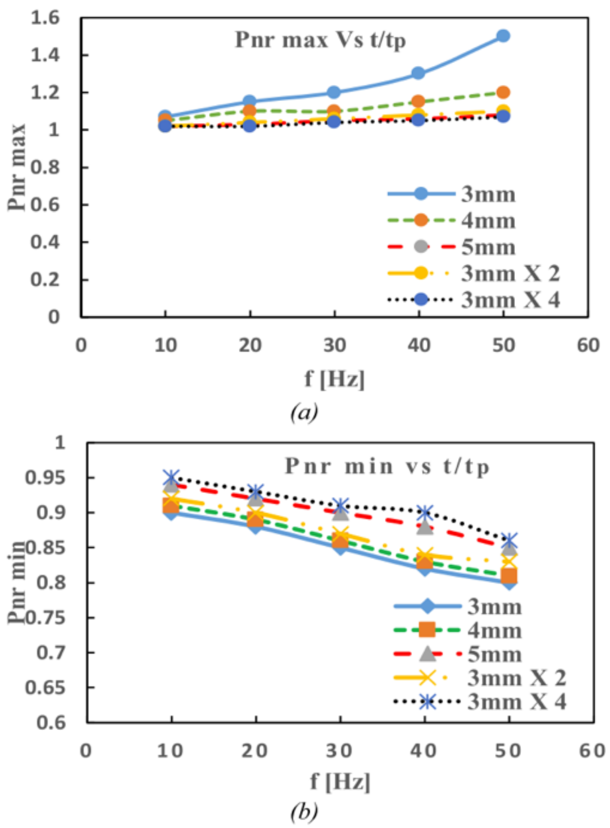

Fig. 3. The highest (a) and lowest (b) normalized cylinder pressures throughout the course of a cycle are displayed versus the actuation frequency [25]

An increase in the pump's flowrate may be accomplished by the strategic use of the vibrator's resonant frequency [19,20]. The best operating frequency of the pump was determined to be somewhere in the range of 2.85–3.15kHz, all of which are rather near to the second order resonant frequency of the vibrator. In order to investigate the cooling impact that the pump has, an open-loop sensing system is being constructed. According to the findings of the tests, the best distance for cooling is 60mm, and the steady temperature is 97.9℃, indicating that there is a considerable cooling impact.

In order to determine whether or not temperature control using the pump is feasible, a closed-loop control system is being constructed. The results of the tests indicate that this system is able to maintain the temperature within the range that was programmed, with an excess of about 0.5℃ at both the top and lower limits. The shorter the interval is, the more often the pump's operating condition changes, the shorter the cooling period is, and the longer the pump operates during each period. Also, the shorter the cooling period is, the faster the pump works during each period [30, 33].

Experimental research of the process of heat transmission inside a heat sink using an impinging synthetic jet while subjected to a variety of sinusoidal and non-sinusoidal wave excitation modes. The simulation was carried out to shed light on the heat transfer process that takes place in the heatsink cavity during the oscillation of the membrane of the initially designed SJA, and the experimental measurements were carried out in order to obtain heat transfer coefficients for a variety of different circumstances. The oscillating movement of the SJA membrane, which occurs throughout one cycle of the excitation wave, creates suction and blowing flow continually, which in turn speeds up the rate at which heat is lost to the environment [33]. According to the findings of this investigation, the impinging synthetic jet that was applied to the heat sink exhibited the best heat transfer characteristics for cooling when the SJA used a 120Hz square wave as its excitation mode. This was determined by comparing the performance of the SJA with various other excitation modes. A square wave with a frequency of 120Hz was found to be the most effective wave excitation mode for cooling the heatsink. This was the primary finding of the research that was published. The major outcome of this conclusion was to give an explanation for this discovery [38,49].

3.2 Distance Between Nozzle and Heater

Miniature electronics are cooled using SJAs to increase heat transfer rate. Vortices penetrate the heated surface's thermal boundary layer, increasing surface turbulence and heat transmission. Unlike traditional fan, the SJ requires no extra fluid supply or sophisticated flow system. SJA is straightforward to use and minimizes thermal management costs. This review examines the influence of SJ actuation, geometrical, and fluid factors on fluid flow and heat transfer. Experimental and numerical studies are needed to understand flow dynamics and thermal performance. The review on heat transfer enhancement yielded the following results:

Few research exists on micro-SJ for cooling miniature electronics devices using piezoelectric diaphragm. Orifice-to-surface distance affects vortex train dynamics and emergence in the thermal boundary layer. Researchers determined that the middle field had the best heat transmission rate.

Heat transfer performance is inversely related to stroke length. At short stroke length, expelled fluid can't transport heat beyond the stagnation point. At high stroke–length, heat transmission occurs more radially than at the stagnation point. At a certain Reynolds number, heat transfer is independent of stroke length. SJ excitation frequency affects heat transfer coefficient and Nusselt number. Maximum cooling performance is attained at resonance frequency at decreased orifice-to-surface distance. The geometrical design of the orifice affects the fluid's mass flow rate. Rectangular orifices maximize heat transmission. Few experimental and computational investigations have addressed how slot Aspect Ratio (AR) affects SJ thermal performance for cooling electronics. The SJA's cavity dimensions, which dictate the swept volume, were similarly understudied. Smaller orifice-to-surface distances increase heat transmission [3,11,29-35]. Heat transmission rate was less affected by cavity shape. Multiple orifices at closer orifice-to-surface distance increase heat transfer coefficient and Nusselt number, which eventually falls. Reynolds number, Prandtl number, excitation frequency, Womersley number, Stokes number, and Strouhal number affect SJA heat transfer and fluid–flow. The average Nusselt number relies on geometrical, non-dimensional characteristics such axial distance, enclosure effect, and average heat transfer distance. Reynolds, Stokes, and Prandtl raise the average Nusselt number, whereas Strouhal and Womersley lower it. The performance of SJA-based heat sinks and microchannels for cooling electrical devices is also studied. SJ-based heat sinks have lower thermal resistance than fan-based ones. Fewer investigations have been done on micro SJA heat sinks and microchannels for active and passive cooling of small devices. In conclusion, additional research is needed to determine the optimal number of SJs, phase angle, and inclination angle for multiple orifices to maximize COP. Existing research gaps and obstacles lead to new paths for SJAs as electronic device coolers [1,44,45].

3.3 Nozzle Shape and Size

It has been determined how the efficiency and the Reynolds number change depending on the diameter of the nozzle. The value of the cavity height has a negative correlation with the value of the efficiency and Reynolds number for natural frequency. The larger the cavity height, the less natural frequency it will produce. The value of the nozzle diameter determines the value of the efficiency as well as the Reynolds number for the natural frequency. The lower the value of the nozzle diameter, the bigger the value. When it comes to Helmholtz efficiency, these dependences are the exact reverse of one another. A synthetic jet actuator that only has one diaphragm exhibits a connection that is analogous to this one [41-45].

We describe the heat transport and acoustic properties of the synthetic jet for both a diamond and an oval shaped orifice. The maximum value of the average heat transfer coefficient was discovered to be 17% higher in the case of a diamond shape orifice and 7% higher in the case of an oval shape orifice at 200Hz when compared to a circular orifice with the same hydraulic diameter. It was found that the aspect ratio of the orifice had a significant impact on the rate of heat transmission. The highest amount of heat that may be dissipated occurs with a diamond and a circular shape of aperture at an axial distance of 48 mm. However, the oval shape of orifice displays the same behavior at an axial distance of 40 mm. Therefore, in the context of decreasing the size of electrical devices, a synthetic jet with an aperture in the form of an oval is a better choice than any other option, despite the fact that it results in a little reduction in heat transmission. According to the findings of the current study and the findings of previous research, it has been found that square and rectangular orifices perform better in terms of heat dissipation across the entire range of axial distance for all different types of orifices. This finding holds true for all different types of orifices. However, oval and diamond shaped orifices function better than circular orifices at smaller axial distances. This is due to the shape of the orifices. The sound pressure level (SPL) of synthetic jets with diamond and oval shaped orifices is about the same, which is 48dB at 200Hz. In contrast, the SPL of synthetic jets with circular shaped orifices is 55dB. When it comes to the design of the necessary cooling solutions for electronic equipment, diamond and oval shapes of orifice are superior choices to circular orifices from both a heat transmission and an acoustic point of view. This is in contrast to circular orifices, which have a circular opening. The SPL that was measured was lower than 40dB at 100Hz, which is within the permitted range according to the USEPA. As a result, a synthetic jet with these orifice shapes may be effectively used for cooling purposes without any further efforts for noise reduction [34].

3.4 Size of Synthetic Jet

The in-phase case that had an orifice spacing of 1 mm had a temperature drop that was far more substantial as time went on. In addition, the out-of-phase case with orifice spacing of 2 mm showed a lower temperature drop for the first eight cycles than the out-of-phase case with orifice spacing of 1 mm did. This was compared to the out-of-phase case where the orifice spacing was 1 mm. On the other hand, the out-of-phase jet arrangement with orifice spacing of 1 mm had hotter water entraining the right cavity during the suction phase. This was because the left jet impinged the thermal boundary layer, which was located extremely near to the right orifice. Because thermal mixing was permitted to take place at a larger distance compared to the similar phasing scenario with orifice spacing of 2 mm, the water that entered the right cavity was colder than it was in the prior example. Therefore, as a result of this, the fluid in the right cavity of the case with 1 mm separation was heated up more quickly than the fluid in the case with 2 mm spacing [36].

As a result of the design of the virtual aperture, the mechanical component of the variable diameter, which was prone to failure as a result of its fatigue, was eliminated. The secondary piston, which was used to actuate the mechanical orifice, was also removed, which resulted in a reduction in the overall noise level of the experimental setup; however, this reduction was not sufficient to generate a change in decibel levels that was significant enough to be measured. The new design, which made use of the virtual aperture, made it possible for testing to go continuously without the need for interruptions caused by failure. The performance of the virtual aperture was not nearly as good as that of its predecessor, the mechanical variable diameter synthetic jet, which was able to achieve an increase in heat transfer rates of up to 35% when compared to the performance of a standard synthetic jet. When compared to a standard synthetic jet, the virtual aperture experienced a rise of no more than around 3% at most. As a result of the design of the virtual aperture, the centerline exit velocity was enhanced by 20% in the simulations. This led to the conclusion that the virtual aperture provided a greater advantage. It turns out that this design's potential uses in the field of heat transfer are not quite as promising as was first believed. Both the laboratory testing and the CFD results confirmed that the suggested virtual aperture does not have the same thermal advantages as the earlier mechanical aperture design and as was predicted. This was established by both sets of findings. It's possible that the advantages of the virtual aperture are lost in the process of getting to the heater. The orifice aperture and the heater are roughly comparable in terms of their sizes. There may be a one-to-one correspondence between the size of the heater and the quantity of heat transfer that is produced by the virtual aperture synthetic jet.

If the heater were smaller, there is a possibility that the thermal enhancement might be increased. To determine if the size of the heater is directly related to the quantity of heat transfer that occurs in the system, more studies are required.

In order to go on with the design of the virtual aperture, the flow behavior will be evaluated via Particle Image Velocimetry (PIV). This will be helpful in determining the differences in flow structures that exist between the synthetic jet with an ordinary aperture and the synthetic jet with a virtual aperture. Depending on the findings of the further testing, the virtual aperture may be put to use in applications involving flow or propulsion [7].

3.5 Size of Piezoelectric

A comparison was made between two piezoelectrically driven central orifice Synthetic Jet Actuators (SJAs) of various sizes (40 mm and 20 mm in diameter) in terms of their heat transfer and noise performance, as well as their diaphragm deflection and nozzle exit velocities from their orifices.

When the diaphragm deflection, jet velocity, and Nu number were all measured when the SJAs were operating close to their structural resonance frequency of the first mode, the results indicated that they were at their highest possible values. When compared to those of ART2000 SJA, the heat-transfer properties of ART4000 SJA were three times more effective based on the peak Nu number. In the range of operating frequencies that were taken into consideration, the synthetic jet regime with respect to stroke length suggested that ART2000 did not form an effective synthetic jet, whereas ART4000 did form an effective synthetic jet in the range of operating frequencies that was considered (200–700 Hz). At an operating frequency that was roughly in the vicinity of their resonance point, the noise produced by both SJAs was at its highest. Because the noise level at a resonance frequency is more than 80 decibels, it is clear that noise dampening is required for applications that take place in the real world. For ART4000, the noise spectrum displayed a peak amplitude at a frequency that is an integral multiple of the resonance frequency; however, this was not the case for ART2000. ART2000's peak amplitude was located at a different frequency. ART4000 was capable of producing an acceptable noise level that was lower than 60dB below an operating frequency of 500 Hz [23].

3.6 Flow Characteristics

Synthetic jets in quiescent fluids have three flow regimes: near-field, transitional, and far-field. In the near-field area, flow structure develops based on discrete vortex rings under time-periodic reverse flow circumstances. Vortex rings entrain ambient fluid into the jet in the transitional area before becoming smaller eddies in the far-field region. Actuator, geometrical, and fluid factors influence synthetic jet performance. Systematically evaluated impacts of geometrical factors on synthetic jets in quiescent flows. Non-circular orifice jets are prone to axis flipping and degrade faster. As the orifice's aspect ratio grew, axis-switching became more violent and occurred farther downstream. A larger aperture has a faster jet exit velocity. When the stimulation frequency is the Helmholtz resonance frequency, the jet's time-averaged velocity is not proportional to the aspect ratio. There's an ideal aspect ratio for maximizing time-averaged velocity.

Studies on orifice depth imply there is an optimal depth for maximal velocity. When orifice depth is less than orifice size, there is no constriction effect, resulting in reduced blowing velocity. At low Helmholtz resonance frequency, orifice depth has little effect on blowing velocity [42-45].

Cavity height varies per SJA type. Some research discovered a negative link between jet velocity and cavity height, whereas others found none. When the diaphragm excitation frequency matched the Helmholtz resonance frequency, the cavity height increased the exit velocity. The two variables were marginally connected when desynchronized.

Maximum jet velocity is related to cavity diameter for a given actuation amplitude. For a given swept volume, the ideal cavity diameter maximizes jet velocity. The greatest average blowing velocity is inversely proportional to the cavity diameter when the excitation frequency is synced with the Helmholtz resonance frequency. Contradictory observations on the impact of rectangular jet aspect ratio on velocity decay rate encourage more study. More aspect ratio levels should be investigated at different stroke ratio ranges for a more thorough study [19,20].

This study covers experimental studies on conjugate heat transfer under a piston-driven synthetic jet and horizontal flow. Frequency and orifice shape affect flow and heat transfer. Such comprehensive conjugate heat transfer measurements have not been published before and should help understand the implications of excitation frequency and orifice geometry [45,49,50].

When the piston reciprocates at low frequency, the time-averaged orifice velocity is proportional to the frequency (from 8 to 24 Hz). Given the same orifice exit area, orifice shape has a smaller influence on synthetic jet exit velocity. The conjugate effect of a synthetic jet and forced flow increases convective heat transfer, particularly at high synthetic jet excitation frequency. When the piston reciprocates at 24 Hz, the peak laterally-averaged convective heat transfer coefficient is raised by 100% for all orifice shapes. Synthetic jet and forced flow conjugate action is optimal at a critical velocity. When the forced flow velocity is below this critical velocity, its contribution to convective heat transfer is decreased. When the forced flow velocity reaches a crucial level, it deflects the synthetic jet and weakens its impingement. Orifice geometry affects the interaction between synthetic jet and horizontal flow. When flow velocity is below 1.81 m/s, the rectangular orifice improves conjugated heat transfer. When flow velocity is more than 1.81 m/s, the round orifice improves conjugated heat transfer [50].

4. Conclusions

This study included a report on the operating concept as well as the selection of the experimental technique. The primary objective was to provide the researcher with a crystal-clear grasp of the path that experimentation studies should take in relation to synthetic jet application problems. It is very necessary to make use of experimentation in order to conduct an accurate analysis of the effectiveness of synthetic jet cooling in real life application. The primary areas of focus for this research were the characteristics of the heat transfer, as well as the characteristics of the flow field. The effect of a change in cavity shape on the oscillation amplitude of pressure arising inside the cavity and the nozzle to place distance may be further discussed in further research as it may also enhance the conditions for heat transfer. This is because changing the shape of the cavity can have an effect on both of these variables.

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