International Journal of Engineering and Computational Applications

Determination of Optimum Operational Jet-to-Jet Spacing of Inline Jets Impingement Heat Transfer

Chukwujindu Sunday
Department of Mechanical and Production Engineering, Enugu State University of Science and Technology, Enugu, Nigeria

* Corresponding Author: **Chukwujindu Sunday**

Article Info

ISSN (Online): 3107-6580
Impact Factor (RSIF): 8.23
Volume: 02
Issue: 03
Received: 26-02-2026
Accepted: 28-03-2026
Published: 30-04-2026
Page No: 31-37

Abstract
This work focuses on the determination of optimum operational jet-to-jet spacing of inline jet impingement heat transfer. Air jet impingement apparatus was used for the exercise. Arrays with the same jet diameter of 0.3mm but of jet-to-jet spacings of 0.9mm, 1mm, 1.2mm, 1.3mm, 1.4mm, 1.6mm, 2mm, 2.2mm, 2.5mm and 3.8mm were tested at flow rates of $1.67 \times 10^{-5} m^3/s$, $3.33 \times 10^{-5} m^3/s$, $5 \times 10^{-5} m^3/s$, $6.66 \times 10^{-5} m^3/s$, $8.3 \times 10^{-5} m^3/s$, $1 \times 10^{-4} m^3/s$, $1.17 \times 10^{-4} m^3/s$ and $1.33 \times 10^{-4} m^3/s$. Each array was tested by hanging it on the aluminium holder of the experimental apparatus. The heating element of wattage capacity 1000Wwas connected to the power source. The heater was switched on to heat the bottom side of the copper plate and the blower was turned on to impinge air on the smooth and flat target plate. Air was regulated to the desired flow rate using a gate valve. The jet temperature as well as the surface temperature were measured using an infrared thermometer at every flow rate tested. Result showed that the optimum jet-to jet spacing was found to be in the range $5d \leq s \leq 7d$.

DOI: https://doi.org/10.54660/.IJECA.2026.2.3.31-37

Keywords: Air jet impingement, jet-to-jet spacing, heat transfer coefficient, infrared thermometer

1. Introduction

Heat transfer in small jet applications has been a topic of growing importance in several engineering disciplines due to its inference in energy productivity, safety, and performance. The flow interactions between the jets and the target surface are included in the composite heat transfer process known as jet impingement (Zakia *et al*., 2025) [16]. Multiple jet impingement has become an established method of convectively cooling or heating surfaces in a wide multiplicity of process and thermal control applications. Impinging jets are extensively utilized in higher heat transfer applications for cooling purposes in various engineering fields such as tempering of glass and metals, heat reduction in microelectronic devices, drying of textiles and papers, gas turbine blades, aircraft deicing (Xie *et al*., 2020) [15]. Dissipation of heat has become a common cause for the thermal runway and breakdown of several electronic devices (Tabassum *et al*., 2022) [14]. To effectively use these devices, it is required to extract heat from the dissipating parts. It is of utmost importance to maintain the electronic device temperature below a specified limit, as overheating may lead to performance degradation, device failure, and even operational hazards in extreme situations. For achieving higher computing efficiency, the devices must be operated in conformity to the thermal safety guidelines. Traditional air-cooling methods often fail to transfer the heat produced by such devices; this impairs the reliability and lifetime of the devices. Badr *et al* (2020) [2] disclosed that multiple jet impingement is a widely implemented convective process for enhancing heat transfer over target surfaces. Impingement cooling is a method of cooling in which a cooling medium is sprayed in the form of a jet onto the surface of the cooled component in order to remove heat. The thickness of the fluid on the target cooling surface of the surface layer results in a high convection heat transfer coefficient, making this a highly stable and effective cooling method (Masip *et al*., 2020) [9].

In general, heat transfer characteristics of multi jets is different from that of the single jets. This is due to the interaction of spent air of the adjacent jets and also due to the interaction between the jets prior to impingement on the plate (Albayrak *et al*., 2023) [1]. Numerous studies have been reported on round jet impingement heat transfer characteristics in an array of multi jets.

Perihan *et al*., (2018) [11] studied the effect of design parameters on a multi jet impinging heat transfer. The test surface is a thin metal sheet which is electrically heated and cooled using an array of nine jets arranged in inline configuration. The range of Reynolds number is 1400 to 41400. The ratio of the distance between the test sheet and nozzle exit (Z/d) is in the range of 1 to 10. The ratio of jet pitch to the jet diameter (S/d) is in the range of 2 to 10. The ratio of the distance between jet exit to the test surface (Z/d) and jet diameter in the range of 2 to 4 have significant effect on the heat transfer. The maximum heat transfer is obtained at (S/d) =6. This result agrees with the result of the present study which shows that the heat transfer coefficient, h increases with increasing jet-to-target distance, H but after a jet-to-target distance of 1.45mm the heat transfer coefficient started decreasing with increasing jet-to-target distance signaling deterioration in heat transfer coefficient. When the value of jet-to-target distance is below 0.85mm deterioration in heat transfer rate also occurred. This deterioration reduces the amount of heat being transferred from the target surface. So, the optimum jet-to-target distance was found to be in the range $5 \leq H/d \leq 6$ and the maximum heat transfer which was 125000 $W/m^2\,^0C$ was achieved at jet-to-target distance of 5d and jet-to-jet spacing of 7d at flow rate of $1.33x10^{-4}m^3/s$.

Ren *et al*., (2021) [12] conducted an experimental investigation into the jet impingement cooling. Their heated plate consisted of a high temperature co-fired ceramic material which measured 70 mm x 20 mm x 1.5 mm and was placed in a square slot carved on the bottom wall of their test chamber. This was aligned with the central axis of the channel. The jets were circular with a diameter of 1.0 mm with a spacing between the jets of 1.8 mm all machined on a 20 mm x 100 mm plate with a thickness of 2 mm. They examined the jet to crossflow velocity ratio as well as the flow and distance from the heated plate. They noted that a critical ratio does exist and that when the jet to plate distance is large, there is often a sharp degradation in the performance. They noted that the array of impinging jets when compared to a single area equivalent jet, was more effective. These results are in agreement with the results of the present study which show that the heat transfer coefficient increases with increasing jet-to-target distance but after a jet-to-target distance of 1.45mm the heat transfer coefficient started decreasing with increasing jet-to-target distance signaling deterioration in heat transfer coefficient. When the value of jet-to-target distance is below 0.85mm deterioration in heat transfer rate also occurred. This deterioration reduces the amount of heat being transferred from the target surface. Also, the cooling performance appears to deteriorate as jet-to-target distance was increased above 3.75mm because the cooling enhancement of the jets was having a lesser effect.

He *et al*., (2022) studied heat transfer enhancement of impingement cooling with corrugated target surface. The surface is electrically heated up to the initial temperature of 800 ^0C. Flow rate is kept constant so that jet Reynolds number remains at Re=24000. Nozzle exit to surface spacing has been changed in a range of z/d = 4-16. For larger surface temperature drop change in nozzle exit to surface spacing does not affect the surface cooling time significantly. However, for lesser surface temperature drop particularly at higher range of surface temperature, surface cooling time is approximately 15 % higher with z/d =4. The surface cooling of a hot stainless-steel surface is experimentally investigated for the stagnation point. At jet Reynolds number of 24000 and for 800 ^0C initial surface temperature it is observed that for larger drop in surface temperature, the cooling time is not affected by the change in nozzle exit to surface spacing. However, for lesser surface temperature drop particularly at higher surface temperature, surface cooling time with nozzle exit to surface spacing is approximately 15 % lower. This result is in line with the result of the present study which shows that the best effective cooling performance was achieved at a H/d = 5 as the target plate was cooled to 20^0C at flow rate of $0.000133m^3/s$. The cooling performance appears to deteriorate as H/d is above 13 because the cooling enhancement of the jets was having a lesser effect. Also, the Cooling performance deteriorates as H/d value was below 3 due to jet-to-target distance being so small that the jets were not forming properly reducing the amount of cooling performances.

Ikhlaq *et al* (2021) [6] studied flow and heat transfer characteristics of turbulent swirling impingement jets. An experimental investigation was carried out to study the behavior of a turbulent air jet impinging on a heated plate. The study of the flow field was performed using a particle image velocimetry. A three-dimensional numerical model with Reynolds stress model has been conducted to examine the global flow. Numerical results agree well with experimental data. The main properties of the fluid occurring between the nozzle and the flat plate are presented. In addition, the effect of the distance between the nozzle exit and the plate (h/e = 14 and 28) were investigated and detailed analysis of the dynamic, turbulent distribution and temperature fields were performed. The wall shear stress and the pressure fields near the heated plate are then explored. Results showed that the mean velocity and the heat transfer characteristics of small nozzle-to-plate spacing are significantly different from those of large nozzle-to-plate spacing. This result agrees with the result of the present study which shows that heat transfer coefficient, h increases with increasing jet-to-target distance, H but after a jet-to-target distance of 1.45mm the heat transfer coefficient started decreasing with increasing jet-to-target distance signaling deterioration in heat transfer coefficient. When the value of jet-to-target distance is below 0.85mm deterioration in heat transfer rate also occurred. This deterioration reduces the amount of heat being transferred from the target surface. Also, as flow rate increases

Oliveira *et al* (2022) [10] carried out experimental study of the heat transfer of single-jet impingement cooling onto a large heated plate near industrial conditions. They studied the effect of nozzle-to-plate spacing on the development of a plane jet impinging on a heated plate. The rise in separation distance resulted in decreased rate of heat transfer as the increase in the separation improves the interaction among the jets and the surroundings, and thus velocity of the jet decreases owing to increased momentum exchange. The values of coefficient of heat transfer as well as Nusselt number decline at stagnation regions. These results are in agreement with the results of the present study in which heat transfer coefficient, h increases with increasing jet-to-target distance, H but after a jet-to-target distance of 1.45mm the heat transfer coefficient started decreasing with increasing jet-to-target distance signaling deterioration in heat transfer coefficient. When the value of jet-to-target distance is below 0.85mm deterioration in heat transfer rate also occurred. This deterioration reduces the amount of heat being transferred from the target surface

Krishan, *et al.*, (2019) [8] studied synthetic jet impingement heat transfer enhancement- a review. They used a stainless-steel plate with the dimensions of 20 mm by 80 mm by 150 mm with an array of 9 K type thermocouples approximately 2.5 mm under the test surface placed 5 mm apart. They found that the improvement offered by jet cooling was largely not dependent on the jet velocity, rather that the system was much more sensitive to the initial temperature of the steel plate. This result is similar to the result of the present study which shows that the best effective cooling performance was achieved at a jet-to-target distance of 1.45mm as the target plate cooled to 20^0C at flow rate of $1.33x10^{-4}m^3/s$.

Chandramohan *et al.*, (2019) [4] optimized heat transfer for high power electronic cooling using arrays of microjets. They experimentally and numerically examined an array of air impinging jets on a heated flat surface in the turbulent regime. Their apparatus consisted of an air inlet with an internal dimeter of 21 mm and a spacing between the nozzles of 30 mm. The nozzles used had an internal diameter of 6 mm. The upper channel had an overall dimension of 36 × 36 × 230 mm and was made of Plexiglas. Their numerical model used a *k*-ε model with low Reynolds number correction for turbulence. They then used a SIMPLEC scheme to couple the velocity and pressure. They noted that decreasing the jet to target spacing resulted in an increase in the experienced heat transfer, as well as lowering the pressure drop of the system. They noted that the fluid velocity decreased as the fluid exited the jet hole resulting from the experienced sheer stresses, with the velocity in the impinging region increasing with a decreasing jet to target distance. This result totally agrees with the result of the present study which shows that the local heat transfer coefficient increases as jet-to-target distance increases from 0.53mm to 1.45mm and starts decreasing thereafter.

Robinson and Schnitzler (2017) [13] Studied an experimental investigation of free and submerged jet array impingement heat transfer. The heat transfer and pressure drop characteristics of jet arrays impinging on a heated surface were investigated for both confined-submerged and free-surface flow configurations. For the submerged jets it was found that the heat transfer is insensitive to changes in the jet-to-target spacing when the nozzle is in close proximity ($2 \leq H/d_n \leq 3$) to the heated surface. For the larger separation distances studied here ($5 \leq H/d_n \leq 20$) the heat transfer deteriorated monotonically with increasing jet-to-target spacing. For a fixed Reynolds number, increasing the spacing between jets also had a serious effect on the heat transfer. A stronger dependence on jet-to-jet spacing was observed for small jet-to-target spacings as compared with larger ones. The free jet configuration was found to behave thermally as a submerged jet within the range of $2 \leq H/d_n \leq 10$. Beyond this, a transition to entirely free-jet flow occurs and the heat transfer coefficient shows marginal improvement with increasing jet-to-target spacing. Consistent with previous investigation, the measurements here indicate that increasing the jet-to-jet spacing, S/d_n, causes a reduction in the heat transfer for a given Reynolds number.

As compared to free-jet flows, the submerged jet configuration at small jet-to-target spacing will provide the required heat transfer coefficient with the smallest pumping power requirement. This result agrees with the result of the present study which shows that the heat transfer coefficient, h increases with increasing jet-to-target distance, H but after a jet-to-target distance of 1.45mm the heat transfer coefficient started decreasing with increasing jet-to-target distance signaling deterioration in heat transfer coefficient. When the value of jet-to-target distance is below 0.85mm deterioration in heat transfer rate also occurred. This deterioration reduces the amount of heat being transferred from the target surface. So, the optimum jet-to-target distance was found to be in the range $5 \leq H/d \leq 6$ and the maximum heat transfer which was 125000 $W/m^2\,^0C$ was achieved at jet-to-target distance of 5d and jet-to-jet spacing of 7d at flow rate of $1.33x10^{-4}m^3/s$.

Ben *et al.*, (2018) have experimentally investigated the flow and the heat transfer characteristics of a round air jet using Particle Image Velocimetry (PIV) technique. The effect of the nozzle distance (h/d = 1 and 2) on the dynamic characteristics and the turbulence behavior is determined. For a fixed Reynolds number, the influence of the distance between the nozzle exit and the flat plate on the stagnation point is well captured. The authors found that when the distance increases, the separation point approaches to the jet axis increases. In addition, the results indicated that the heat transfer coefficient increases with increasing flow rate. This result agrees with the result of the present study in which jet-to-target distance, H/d increases but start reducing after H/d of 4.83.

Jung-Yang and Jenq-Jye (2018) [7] studied the effects of jet-to-jet spacing and jet height on heat transfer characteristics of an impinging jet array. The Nusselt number distributions for five confined circular air jets vertically impinging on a flat surface were measured. The jet-to-jet spacing to jet diameter ratio (s/d) and the jet height to jet diameter ratio (H/d) were in the range of 2.0-8.0 and 0.5–3.0 respectively. The jet Reynolds number was 20,000. At small s/d and H/d values (s/d = 2.0 and H/d = 0.5), a maximum Nu, attributed to a strong flow impact (jet interaction) on the impingement plate, was clearly observed between the middle jet and every neighboring jet. The jet interaction decreases with an increase of the s/d and H/d. Jet interference before impingement causes a decrease in heat transfer. However, it achieves a uniform Nusselt number distribution in the region directly covered by the jet array. At intermediate s/d and large H/d values (s/d = 4.0 and H/d = 2.0), both the jet interaction and jet interference are weak, but the expelled air of the middle jet (cross flow) reduces the heat transfer of the neighboring jets. At large s/d values (s/d = 6.0), regardless of the H/d value (in the range of 0.5–3.0), every jet possesses an independent cooling area on the impingement plate.

2. Materials and Methods

2.1. Materials

The materials used in this study were copper plate of size 20mm x 20mm and thickness 1mm, heating element (Nichrome wire of capacity 120V, 1KW), air cylinder of volume $40m^3$, 0.5hp centrifugal blower, PVC pipe of 20mm diameter, aluminum plate of thickness 3mm, strain gage-type pressure transducer of 5mA, 3Vdc, infrared thermometer (FLIR Lepton 3.0) and gage valve.

2.1.1. Experimental Apparatus

An experimental apparatus consists of a heater assembly, a 0.5hp centrifugal blower, an air cylinder, PVC pipe, jet nozzle plate, flow control valves, pressure transducer, and infrared thermometer.

A plane jet of air impinging on a heated smooth flat surface is produced by the apparatus shown in plate 1. The jet emerged from a circular nozzle (20 mm diameter). The target surface which represents the surface of a typical electronic device was made of copper, of dimensions 20mm x 20mm and thickness 1mm and is heated using the heater, wattage capacity of 1000W. Copper is selected because of its high thermal conductivity. Jet nozzle plates having 0.3mm diameter holes were used. The holes are laser drilled and arranged in a square array of $11 \times 11$with jet-to-jet spacing of 0.9mm, 1mm, 1.2mm, 1.3mm, 1.4mm, 1.6mm, 2mm, 2.2mm, 2.5mm and 3.8mm. The distance between the jet nozzle plate and the test plate surface is maintained at 1.45mm. The air flow rate, and impingement plate were varied during the experiments.

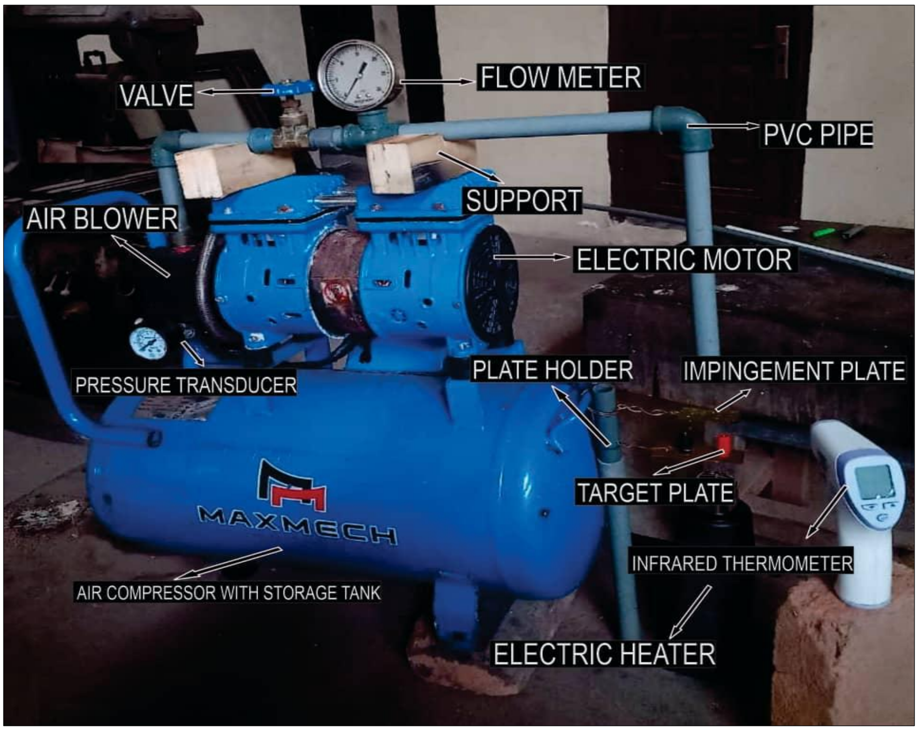

Fig 1: Experimental apparatus

2.1.2. Heat Transfer Measurement and Quantification

The heat transfer coefficient at the heated surface is giving as (Amjadian *et al*., 2020)

$$h = \frac{P}{A\Delta T} = \frac{P}{A\left(T_{s}-T_{j}\right)} \quad (1)$$

Where,

h is heat transfer coefficient (W/m^2 ^{o}C)

P is heat transfer in Watts

A is heat transfer surface area {m^2)

T_s is target surface temperature (^{o}C)

T_j is the jet temperature (^{o}C)

2.1.3. Optimal Operational Jet-to-Jet Spacing of Inline Jet Array Impingement Heat Transfer.

The jet-to-jet spacing at which jet array produces the best both in cooling and in heat transfer coefficient is established as the optimal operational jet-to-jet spacing (Badr *et al*., 2025).

The jet-to-jet spacing used for the test are listed in table 1 while their diagrams are shown in figure.1.

Table 1: Jet-to-jet spacing

Letter	Array	s (mm)	d (mm)	s/d
A	11×11	0.9	0.3	3.00
B	11×11	1.0	0.3	3.33
C	11×11	1.2	0.3	4.00
D	11×11	1.3	0.3	4.33
E	11×11	1.4	0.3	4.67
F	11×11	1.6	0.3	5.33
S	11×11	2.0	0.3	6.67
G	11×11	2.2	0.3	7.33
H	11×11	2.5	0.3	8.33
I	11×11	2.8	0.3	9.33

Table 1 shows array 11×11 of different jet-to-jet spacings but of the same jet diameter.

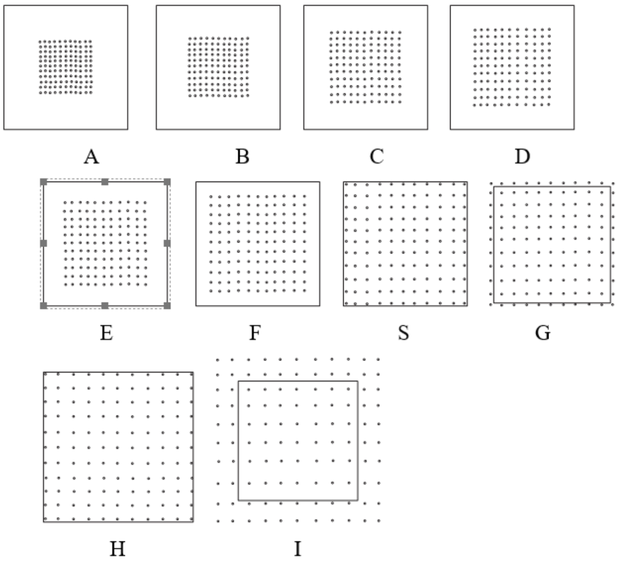

Fig 1: Arrays with letters A, B, C, D, E, F, S, G, H, I. having jet-to-jet spacing of 0.9mm, 1mm, 1.2mm, 1.3mm, 1.4mm, 1.6mm, 2mm, 2.3mm, 2.5mm and 2.8mm respectively.

The arrays were tested to determine the effect of jet-to-jet spacing on cooling and heat transfer coefficient performances.

2.2. Experimental Procedure

We started by hanging an array with letter A with jet diameter and jet spacing of 0.3mm and 0.9mm respectively on an aluminium holder at a jet-to-target distance of 1.45mm, and connected the heating element to the power source with current and voltage maintained at 8.3A and 120V respectively. The heater was switched on to heat the target plate. Instantaneously, heat was supplied at the bottom side of the plate and except top surface other sides were insulated perfectly using electrical insulating material to prevent electrical contact of the heater with the plate and the blower was turned on to impinge air on the smooth and flat target plate. We ensured that air was regulated to the desired flow rate using gate valve. We captured the jet temperature, T_j before the air impinges on the target plate and captured also the surface temperature, T_s after the target plate had reached a steady state using infrared thermometer. Temperature change, ΔT that is $(T_s - T_j)$ was calculated and equation 1 was used to calculate the heat transfer coefficient.

We continued the experiment till every array listed in figure 1 was tested at flow rate of $1.67\text{x}10^{-5}\text{m}^3/\text{s}$, $3.33\text{x}10^{-5}\text{m}^3/\text{s}$, $5\text{x}10^{-5}\text{m}^3/\text{s}$, $6.66\text{x}10^{-5}\text{m}^3/\text{s}$, $8.3\text{x}10^{-5}\text{m}^3/\text{s}$, $1\text{x}10^{-4}\text{m}^3/\text{s}$, $1.17\text{x}10^{-4}\text{m}^3/\text{s}$ and 1.33x10-4m3/s. At each test performed, the required parameters were noted and calculated.

3. Results and discussion

3.1. Optimal operational jet-to-jet spacing of inline jets impingement heat transfer.

The result of optimal operational jet-to-jet spacing of inline jets impingement heat transfer is discussed in these sessions**.**

3.1.1. Effect of jet-to-jet spacing on cooling performance.

The temperature rise versus jet-to-jet spacings of 0.9mm, 1mm, 1.2mm, 1.3mm, 1.4mm, 1.6mm, 2mm, 2.2mm, 2.5mm and 3.8mm at flow rates of $1.67\text{x}10^{-5}\text{m}^3/\text{s}$, $3.33\text{x}10^{-5}\text{m}^3/\text{s}$, $5\text{x}10^{-5}\text{m}^3/\text{s}$, $6.66\text{x}10^{-5}\text{m}^3/\text{s}$, $8.3\text{x}10^{-5}\text{m}^3/\text{s}$, $1\text{x}10^{-4}\text{m}^3/\text{s}$, $1.17\text{x}10^{-4}\text{m}^3/\text{s}$ and $1.33\text{x}10^{-4}\text{m}^3/\text{s}$ is shown in figure 2. Result showed that when the jet-to-jet spacings were compared the best effective cooling performance was achieved at a jet-to-jet spacing of 2mm at which the target plate cooled to 54^{o}C, 48^{o}C, 42^{o}C, 37^{o}C, 34^{o}C, 32^{o}C, 30^{o}C, and 27^{o}C at flow rates of $1.67\text{x}10^{-5}\text{m}^3/\text{s}$, $3.33\text{x}10^{-5}\text{m}^3/\text{s}$, $5\text{x}10^{-5}\text{m}^3/\text{s}$, $6.66\text{x}10^{-5}\text{m}^3/\text{s}$, $8.3\text{x}10^{-5}\text{m}^3/\text{s}$, $1\text{x}10^{-4}\text{m}^3/\text{s}$, $1.17\text{x}10^{-4}\text{m}^3/\text{s}$ and $1.33\text{x}10^{-4}\text{m}^3/\text{s}$ respectively. The second best effective cooling performance was achieved at a jet-to-jet spacing of 1.6mm at which the target plate cooled to 60^{o}C, 50^{o}C, 44.7^{o}C, 39^{o}C, 35.55^{o}C, 33.56^^{o}C, 31^{o}C, 29.30^{o}C at flow rates of $1.67\text{x}10^{-5}\text{m}^3/\text{s}$, $3.33\text{x}10^{-5}\text{m}^3/\text{s}$, $5\text{x}10^{-5}\text{m}^3/\text{s}$, $6.66\text{x}10^{-5}\text{m}^3/\text{s}$, $8.3\text{x}10^{-5}\text{m}^3/\text{s}$, $1\text{x}10^{-4}\text{m}^3/\text{s}$, $1.17\text{x}10^{-4}\text{m}^3/\text{s}$ and $1.33\text{x}10^{-4}\text{m}^3/\text{s}$ respectively.

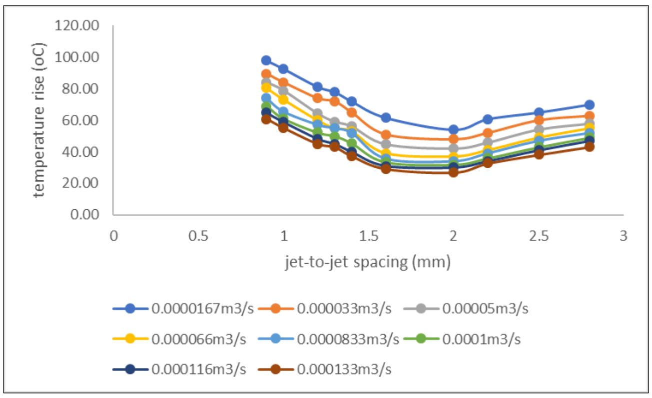

Fig 2: Temperature rise against jet-to-jet spacing

Result also showed that cooling performance appears to worsen as jet-to-jet spacing was above 2.5mm because the cooling enhancement of the jets was having a lesser effect. Array jet with close jet-to-jet spacing causes increase in jet-to-jet interaction. Result also showed that the cooling performance depreciate as jet-to-jet spacing decreased below 1.2mm due to jet-to-target distance being so small that the jets were not forming properly reducing the amount of cooling performances. The jet-to-jet spacing of 1.6mm is 5 jet diameters whereas the jet-to-jet spacing of 2mm is approximately 7 jet diameters. Therefore, the optimum jet-to-jet spacing is found to be in the range 1.6mm ≤ s ≤ 2mm or 5d ≤ s ≤ 7d or 5 ≤ s/d ≤ 7.

3.1.2. Effect of jet-to-jet spacing on heat transfer coefficient.

The heat transfer coefficient versus jet-to-jet spacing of 0.9mm, 1mm, 1.2mm, 1.3mm, 1.4mm, 1.6mm, 2mm, 2.2mm, 2.5mm and 3.8mm at flow rates of $1.67x10^{-5}m^3/s$, $3.33x10^{-5}m^3/s$, $5x10^{-5}m^3/s$, $6.66x10^{-5}m^3/s$, $8.3x10^{-5}m^3/s$, $1x10^{-4}m^3/s$, $1.17x10^{-4}m^3/s$ and $1.33x10^{-4}m^3/s$ is shown in figure 3. Result showed that when these jet-to-jet spacings were compared, the highest value of heat transfer coefficient was achieved at a jet-to-jet spacing of 2mm at every flow rate tested. The heat transfer coefficient at this jet-to-jet spacing of 2mm were 46296W/m^{2o}C, 52083 W/m^{2o}C, 59524 W/m^{2o}C, 67568 W/m^{2o}C, 73529 W/m^{2o}C, 78125 W/m^{2o}C, 83333 W/m^{2o}C, and 92593 W/m^{2o}C at flow rates of $1.67x10^{-5}m^3/s$, $3.33x10^{-5}m^3/s$, $5x10^{-5}m^3/s$, $6.66x10^{-5}m^3/s$, $8.3x10^{-5}m^3/s$, $1x10^{-4}m^3/s$, $1.17x10^{-4}m^3/s$ and $1.33x10^{-4}m^3/s$ respectively. The second highest value of heat transfer coefficient occurred when the jet-to-jet spacing was 1.6mm, and the values were 41667 W/m^2 ^{o}C, 50000 W/m^{2o}C, 55928 W/m^{2o}C, 64103 W/m^{2o}C, 70323 W/m^{2o}C, 74493 W/m^{2o}C, 80645 W/m^{2o}C and 85324 W/m^2 ^{o}C at flow rates of $1.67x10^{-5}m^3/s$, $3.33x10^{-5}m^3/s$, $5x10^{-5}m^3/s$, $6.66x10^{-5}m^3/s$, $8.3x10^{-5}m^3/s$, $1x10^{-4}m^3/s$, $1.17x10^{-4}m^3/s$ and $1.33x10^{-4}m^3/s$ respectively.

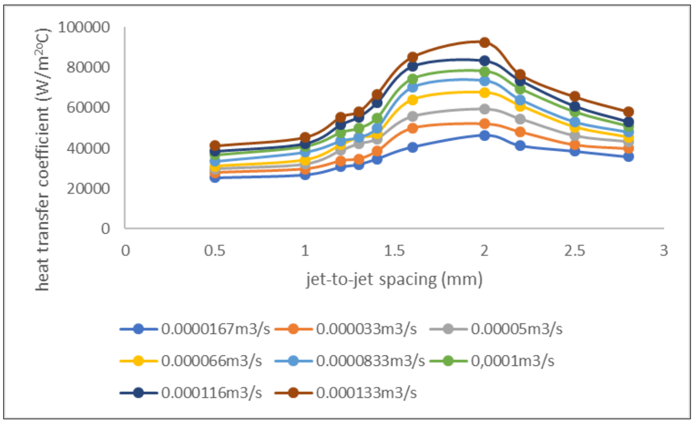

Fig 3: Heat transfer against jet-to-jet spacing

The jet-to-jet spacing of 1.6mm is 5 jet diameters whereas the jet-to-jet spacing of 2mm is approximately 7 jet diameters. Therefore, the optimum jet-to-jet spacing is found to be in the range 1.6mm ≤ s ≤ 2mm or 5d ≤ s ≤ 7d or 5 ≤ s/d ≤ 7.

Result also showed that at each flow rate tested heat transfer coefficient increased with increasing jet-to-jet spacing but this increase stopped at jet-to-jet spacing of 2mm, then deceased as jet-to-jet spacing increased. So, the highest heat transfer coefficient occurred when the jet-to-jet spacing was 2mm.

4. Conclusion

The present study provides a good understanding of cooling performance and heat transfer characteristics of air impinging jets. Experiments were conducted to determine the optimum operational jet-to-jet spacing of inline impingement heat transfer. Result showed that the optimum jet-to-jet spacing is found to be in the range 1.6mm ≤ s ≤ 2mm or 5d ≤ s ≤ 7d or 5 ≤ s/d ≤ 7.

Table 2:

Symbol	Description	Unit
A	Heat transfer surface area	m²
d	Jet diameter	mm
h	Heat transfer coefficient	W/m² °C
P	Power	W
Tj	Temperature of the jet	°C
Ts	Temperature of the surface	°C
Q	Volume flow rate	m³/s

References

1. Albayrak M, Sarper B, Saglam M, Birinci S, Aydin O. The role of jet-to-crossflow velocity ratio on convective heat transfer enhancement in the cooling of discrete heating modules. Therm Sci Eng Prog. 2023;37:101549.
2. Badr MA, Lioua K, Hacen D. CFD analysis of heat transfer enhancement in impinging jet array by varying number of jets and spacing. Int J Gas Turbine Propuls Power Syst. 2020;4:23–37.
3. Ben KR, Habli R, Mahjoub SN, Bournot H, Le PG. Parametric analysis of a round jet impingement on a heated plate. Int J Heat Fluid Flow. 2018;57:11–23.
4. Chandramohan P, Murugesan SN, Arivazhagan S. Experimental investigation and CFD analysis of influence of swirl, arrangement of nozzle, cross section and diameter of jets on heat transfer in multi-jet air impingement cooling. J Therm Sci. 2019;23:25–35.
5. He J, Deng Q, Feng Z. Heat transfer enhancement of impingement cooling with corrugated target surfaces. Int J Therm Sci. 2022;17:91–123.
6. Ikhlaq M, Al-Abdeli YM, Khiadani M. Flow and heat transfer characteristics of turbulent swirling impingement jets. Appl Therm Eng. 2021;196:20–30.
7. Jung-Yang S, Jenq-Jye C. Effect of jet-to-jet spacing and jet height on heat transfer characteristics of an

impinging jet array. Elsevier Ltd; 2018.
8. Krishan G, Sharma RN. Synthetic jet impingement heat transfer enhancement: A review. Appl Therm Eng. 2019;149:305–323.
9. Masip Y, Campo A, Nunez SM. Experimental analysis of the thermal performance on electronic cooling by a combination of cross-flow and an impinging air jet. Appl Therm Eng. 2020;167:45–57.
10. Oliveira AVS, Marechal D, Borean JL, Schick V, Denis S, Gradeck M. Experimental study of the heat transfer of single-jet impingement cooling onto a large heated plate near industrial conditions. Int J Heat Mass Transf. 2022;47:231–243.
11. Perihan C, Nevin C, Kazim P. Effect of design parameters on a multi-jet impinging heat transfer. Alex Eng J. 2018;34:78–111.
12. Ren X, Yang X, Lu X, Li X, Ren J. Experimental investigation of micro cooling units on impingement jet array flow pressure loss and heat transfer characteristics. Int J Heat Mass Transf. 2021;14(16):87–101.
13. Robinson AJ, Schnitzler E. An experimental investigation of free and submerged miniature liquid jet array impingement heat transfer. J Heat Mass Transf. 2017;25:126–135.
14. Tabassum S, Hilfer M, Brakmann RG, Willert CMC, Matha M, Schroll M. Validation and assessment of computational fluid dynamic modeling of multi-jet impingement cooling with experiments. In: ASME Turbo Expo: Turbomachinery Technical Conference and Exposition; 2022. p. 12.
15. Xie G, Liu CL, Ye L, Wang R, Niu JJ, Zhai YN. Effects of impingement gap and hole arrangement on overall cooling. Int J Heat Mass Transf. 2020;152:119249.
16. Zakia R, Nidhal H, Aboulbaba E, Badr MA, Lioua K, Hacen D. CFD analysis of heat transfer enhancement in impinging jet array by varying number of jets and spacing. Int J Gas Turbine Propuls Power Syst. 2025;14:119–140.

How to Cite This Article

Chukwujindu S, Onah TO, Aka CC. Determination of optimum operational jet-to-jet spacing of inline jets impingement heat transfer. International Journal of Engineering and Computational Applications. 2026;2(3):31–37. doi:10.54660/.IJECA.2026.2.3.31-37.