10.48047/jocaaa.2024.33.08.170

CORRELATIVE ANALYSIS ON HEAT TRANSFER EQUATIONS IN FORCED FLUID FLOW

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ABSTRACT

Forced convective heat transfer for laminar flow and turbulent flow in single channel and multiple channels have been examined experimentally with air blown in both flow modes in order to find the best solution for heat mitigation that arises commonly in most of high dense electronic circuits. The heat transfer characteristics were derived for the customized heating element enclosed within a enclosure by providing corrections in radiation and natural convection. Various metrics like Reynolds number, Nusselt number and heat transfer coefficient were derived and compared with the similar literature inference. The experimental results of the proposed methodology exhibit a profound behavior in terms of Reynolds number. Thus correlative analysis of the Nusselt number and the Reynolds number has been provided with the best outcome for the novel innovative technique based on heat transfer equations.

Keywords: System-on-Chip; Thermal Management; Forced Convection; Reynolds Number; Nusselt Number; Newton's Law of Cooling.

1. MOTIVATION AND RELATED RESEARCH

Recent days, Electronic components with high functionality is favored for compact size and high end applications. The compactness could be achieved by integrating the most of the or entire functional units in a single chip. This evolution gives rise to the magnificent use of System-on- Chip(SoC) in most of the electronic devices ranging from mobile phones, satellites, radar systems and even in telehealth instrumentation. The major bottleneck in the SoC is the intent heat that produced at the ends of the device due to the highly dense systems within a slim area [1].Various mechanisms have been employing by the recent researchers to reduce the heat and save the device from malfunctionalities and even system crash [5,6]. The Proposed methodology provides a novel pilot work for thermal management in the high dense systems

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than the conventional cooling methods that are discussed in [2-4].This methodology was equated with the governing equations and the results were validated with valid metrics. Most of the thermal concise electronic systems fail due to the high temperature that inherent in the high end systems. The proposed system provides the platform to examine the thermal characteristics of air as coolant.

2. WORKING UNIT MODELING

The proposed model consists of a customized working unit which is attached with temperature sensor to monitor the temperature of the heating element which is fed with external power supply. The input power is utilized to heat up the working unit over time and the heat generated is examined using the attached temperature sensor. The other parameters like voltage, current of the model are examined by the voltage and current sensor at the controlling unit.The modelling module consists of a controlling unit where the various sensors are controlled using the controller kit. The system works in DC environment as in most of the electronic equipments, in which the power dissipated of the system is directly proportional to input voltage applied to the system from the below equation(1). The power applied to the system is dissipated in the form of external heat that was generated from the device.

$P = V_{in} * I$ (1)

The dimensions of the customized heating element with ceramic material to simulate silicon chip, which is densely occupied with high functionality units.The schematic view of the architecture of the working model with arrangement of sensors attached with it in order to collect, display in the I/O Device and recorded in cloud is exhibited in Fig.2. After the working model entered into the heating phase, it has to be cooled with the coolant that is blown using the external blower. Various modes of coolant flow is shown in Fig.1 to Fig.4 The air is taken as coolant and the properties are shown in the Table1.

During the cooling phase, the working unit is exposed to the coolant through four modes of fluid flow. The coolant flow is catalysed by the externally connected blower, which corresponds the fan which is present in electronic equipments. The Coolant flow system is characterized by various parameters and is shown clearly in Table.2. The flow rate of the blown coolant is monitored by the flow rate sensor attached in the controlling module.

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Table:1 Properties of Coolant

PROPERTIES OF AIR AS COOLANT		
Attribute	At 25°C	At 30°C
Density (ρ)	1.1845 kg/m^3	1.1649 kg/m^3
Dynamic Viscosity (μ)	1.844x10^{-5} kg/m.s	1.8680x10^{-5} kg/m.s
Kinematic Viscosity (v)	1.5571x10^{-5} m^2/s	1.6036x10^{-5} m^2/s
Specific Heat Capacity (cp)	1.0063x10^3 J/kg.K	1.6036x10^3 J/kg.K
Thermal Conductivity (k)	0.025969W/m.K	0.026341W/m.K
Prandtl Number (Pr)	0.71465	0.71375

(Courtesy : content from "Fundamentals of Engineering Thermodynamics" book as in [7])

Case (i) Single Channel Laminar Flow

Here, the coolant is blown from the blower through the coupler to the single outlet tube,which is connected to cool the heating element which is shown in the figure, Fig.1

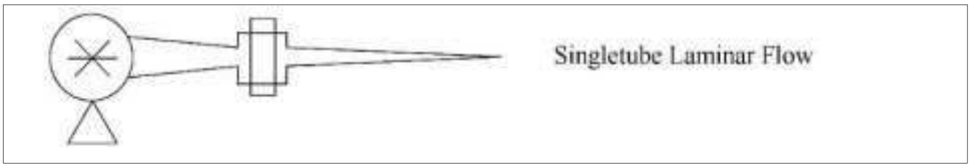

Fig.1 Pictorial representation of case (i)

Case (ii) Multiple Channel Laminar Flow

In this case, the coolant is blown from the blower through the coupler to three outlet tubes,which is connected to cool the heating element which is shown in the figure, Fig.2. This increase of channel multiples the fluid flow due to proximity and enhances the heat mitigation effect.

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Fig.2 Pictorial representation of case (ii)

Case (iii) Single Channel Turbulent Flow

In this type, the coolant is blown from the blower through the coupler to the single outlet tubes,which is connected to cool the heating element which is shown in Fig.3. Here the coolant conducting tube is replaced with the twisted tube to provide the turbulence in the coolant.

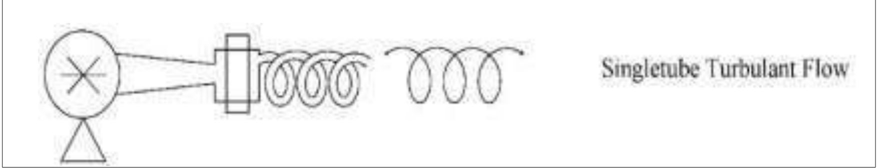

Fig.3 Pictorial representation of case (iii)

Case (iv) Multi Channel Turbulent Flow

In this mode, the coolant is blown from the blower through the coupler to three twisted outlet tubes,which is connected to cool the heating element which is shown in Fig.4. Both the advantage of close proximity of multiple channels and turbulence expedite the cooling process than the above three modes of fluid flow.

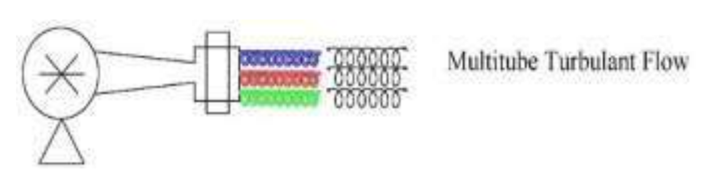

Fig.4 Pictorial representation of case (iv)

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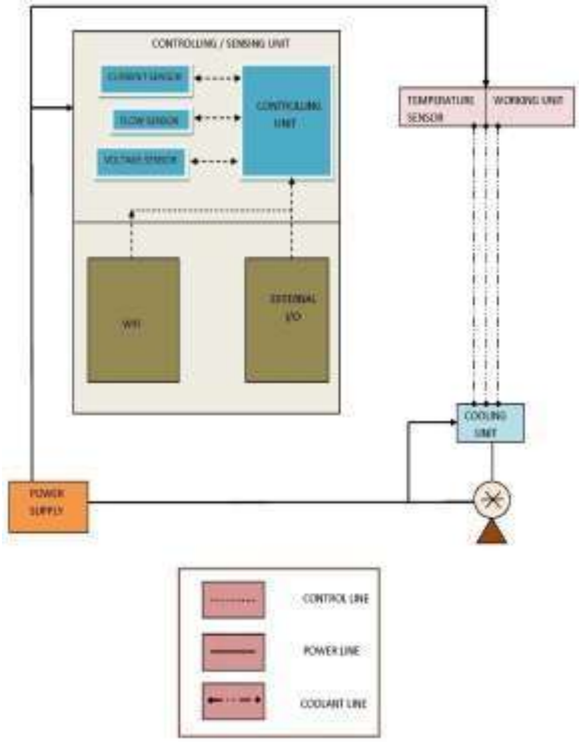

Fig. 5Schematic View of working model

Table:2 Characteristics of Cooling Module

WORKING ENVIRONMENT OF FLUID FLOW	
Parameter	Value
Diameter of fluid flow duct	7 mm
Length of fluid flow duct	170 mm
Maximum Flow rate of Blower	35 Lit./min
Maximum Pressure of Blower	0.024 MPa

Table.3: Examination on four modes of cooling methodology

Methodology	**Average Drop in temperature per minute (°C)**
Single channel Laminar flow	5.7
Single channel Turbulent flow	9.8
Multi channel Laminar Flow	7.6
Multi channel Turbulent Flow	11.1

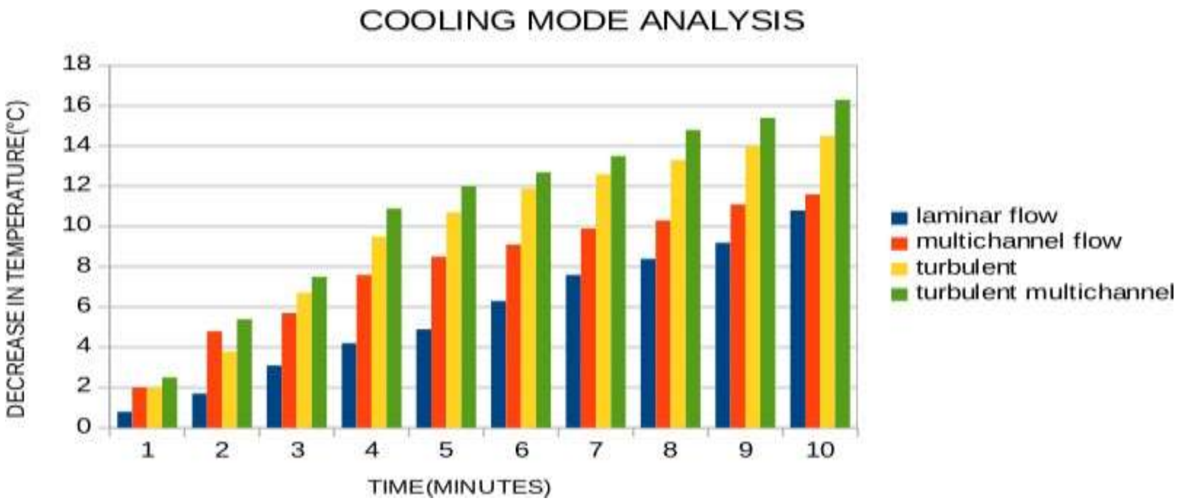

Fig.6 Comparison of results in four modeling Cases

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3. DERIVATION OF HEAT TRANSFER EQUATIONS

The modeling unit is intended to verify with the basic governing equations like newton’s law of cooling.The governing equations for the forced convection in the proposed system lies on Newton’s Law of cooling, which could provide delibrate solution to verify the heat transfer characteristics as in [8].The transfer characteristics due to natural convection and radiation may be of less or no significance in the working model and hence the heat transfer characteristics is derived here is based on the assumption of forced convection factor ignoring the radiation and natural convection.

As per the Newton’ s Law of cooling, the rate of Heat transfer by convection is given by $Q = h*A*(\Delta T)$ (2)

where Q refers the heat transferred per unit time, *A* denotes the area of fluid flowing duct, *h* refers the heat transfer coefficient, ΔT is the temperature difference. The convective heat transfer coefficient (h)strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent). The estimated ‘h’ values for the proposed system is shown in the Fig.7

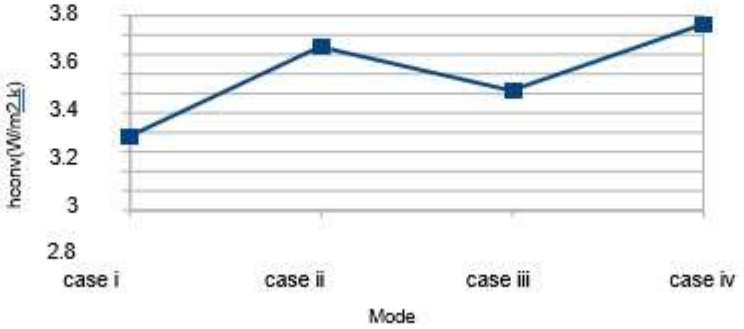

Fig.7 Heat Transfer Coefficient (h_{conv} in $W/m^2.k$) for the four modes of operation

Based on the computed heat transfer cooeffiecient, ‘ h’ values for the given system, it is clearly verified that the rate of cooling is high and compromising thermal solution is given by the Case ii and Case iv arrangement of fluid flow.

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Will et.al in [9] shows that very important and significant method of examining the fluid flow mode is by the way of Reynolds number (Re) and Nusselt Number (Nu) and many researchers interpreted these two dimensionless quantities to characterize the heat transfer measures. Equation (3) derives the relationship between the geometric dimensions and viscous force of the system.

Reynolds Number, Re = V* L*D/ viscosity -------------------------------------- (3)

The modeling elements provide the values of rate of fluid flow from the flow sensor in the working module is used for the calculation of Re and corresponding values of Re is shown in Fig.8 and the same could be used for the Re calculation based on velocity as depicted in Fig.9

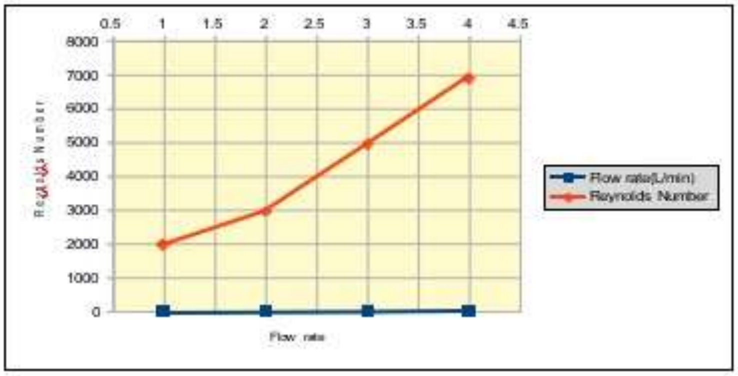

Fig.8 correlation between Flow rate and Re

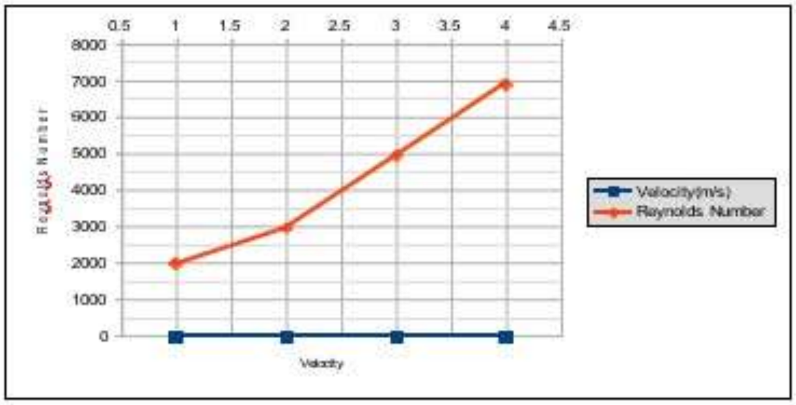

Fig.9 correlation between Velocity and Re

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Wang et.al in paper[11] examined the heat transfer characteristics of longitudinal rows of tubes with different dimensions,(which could be compared with multichannel flow of proposed methodology) with Reynolds numbers of 100 and 300 and a Prandtl number of 0.71.Anurag dahiya et.al in paper[12] examined heat sinks with manifolds and derived Reynolds number for turbulent flow in the range of 342–857. The valid comparison of proposed work and inference from various literatures could be depicted in Fig.10

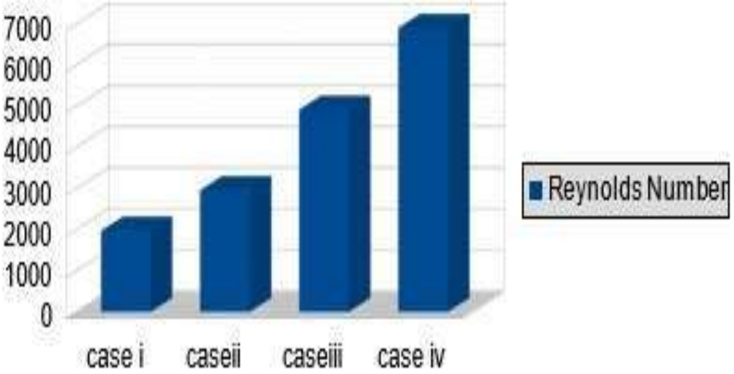

Fig. 10 Comparison of Results for the forced convection heat transfer based on Reynolds number

The another metric used for heat transfer analysis is the derivation of Nusselt Number, Nu which is the function of Reynolds Number(Re) and Prantl Number(Pr) which is shown in Equations (4),(5)

$Nu=\{Re,Pr\}$ -- (4)

Nusselt Number is given by $Nu=0.683\ Re_{0.466}\ Pr_{1/3}$ ----------------- (5)

The impact of the nusselt number Nu for the four modes of the proposed methodology is depicted in Fig.8 and Fig.9 shows the relationship between Nu and Re.

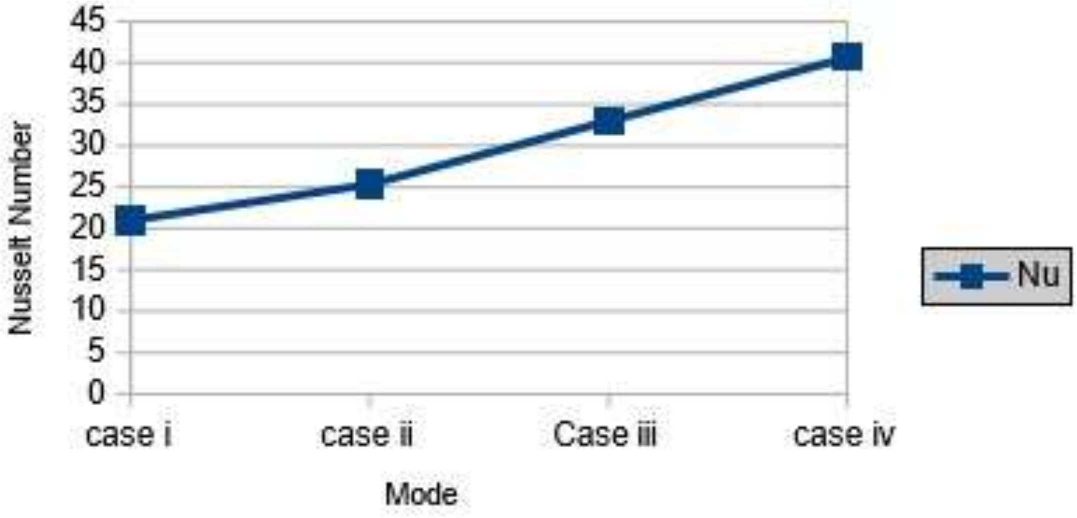

Fig. 11 Comparison of Results for the forced convection heat transfer based on Nu

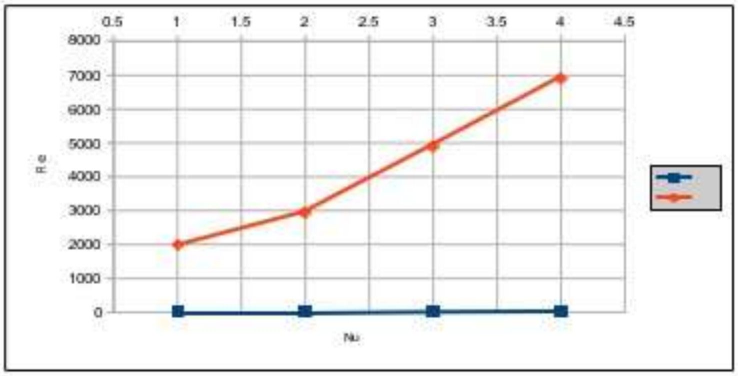

Fig.12 Relating Re and Nu of the proposed methodology

4. CONCLUSION

This paper provides an exemplary solution for the thermal aware systems in order to prevent the electronic devices from malfunction by employing the provision of multi-channel ducts using nano tubes during the design and manufacturing phase. The heat transfer coefficient 'h' value derived from the proposed system has achieved the value of 37 W/m^2.K in the multichanneled turbulent

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flow of fluid flow. The Reynolds number results with value from 1974(case i) to 6912 (case iv) shows the higher contribution of turbulent regime. This value is very much higher than values in [11] and [12]. Next, the active contribution of turbulent flow is exhibited from the Nusselt number with the value of 40 in multi channel turbulent flow.The proposed work exhibits the excellent heat mitigation effects by verifying the results with heat transfer metrics in forced convection fluid flow. Thus the correlative analysis of the values stands good in forced convection with turbulent air as coolant in multiple channels.

REFERENCES

[1] B. R. Ramesh Bapu, S. Kayalvizhi, and S. Murugavalli, “Two phase cooling with nano-fluid for highly dense systems,” *Microelectronics Reliability*, vol. 103, 113640, 2020. https://doi.org/10.1016/j.microrel.2020.113640

[2] Y. Yoon, D. R. Kim, and K.-S. Lee, “Cooling performance and space efficiency improvement based on heat sink arrangement for power conversion electronics,” *Applied Thermal Engineering*, vol. 164, 114458, 2020. https://doi.org/10.1016/j.applthermaleng.2019.114458

[3] M. A. A. Japar, N. A. C. Sidik, and S. Mat, “A comprehensive study on heat transfer enhancement in microchannel heat sink with secondary channel,” *International Communications in Heat and Mass Transfer*, vol. 98, pp. 62–81, 2018. https://doi.org/10.1016/j.icheatmasstransfer.2018.10.005

[4] H.-T. Chen, Y.-L. Hsieh, P.-C. Chen, Y.-F. Lin, and K.-C. Liu, “Numerical simulation of natural convection heat transfer for annular elliptical finned tube heat exchanger with experimental data,” *International Journal of Heat and Mass Transfer*, vol. 127, pp. 541–554, 2018. https://doi.org/10.1016/j.ijheatmasstransfer.2018.08.057

[5] R. Dash, A. Majumdar, V. Pangracious, A. K. Turuk, and J. L. Risco-Martin, “ATAR: An Adaptive Thermal-Aware Routing Algorithm for 3-D Network-on-Chip Systems,” *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 8, no. 12, pp. 2122–2129, 2018. https://doi.org/10.1109/TCPMT.2018.2842102

[6] G. Liang and I. Mudawar, “Review of single-phase and two-phase nanofluid heat transfer in macro-channels and micro-channels,” *International Journal of Heat and Mass Transfer*, vol. 136, pp. 324–354, 2019. https://doi.org/10.1016/j.ijheatmasstransfer.2019.02.086

10.48047/jocaaa.2025.34.05.26

[7] J. Martin, M. Bailey, M. Moran, and H. Shapiro, *Fundamentals of Engineering Thermodynamics*, 8th ed. Wiley.

[8] J. Rosales-García, J. A. Andrade-Lucio, and O. Shulika, "Conformable derivative applied to experimental Newton's law of cooling," *Revista Mexicana de Física*, vol. 66, no. 2, pp. 224–227,
2020. https://doi.org/10.31349/RevMexFis.66.224

[9] J. B. Will, N. P. Kruyt, and C. H. Venner, "An experimental study of forced convective heat transfer from smooth, solid spheres," *International Journal of Heat and Mass Transfer*, vol. 109, pp. 1059–1067, 2017. https://doi.org/10.1016/j.ijheatmasstransfer.2017.02.018

[10] T. Yuge, "Experiments on heat transfer from spheres including combined natural and forced convection," *Journal of Heat Transfer*, vol. 82, pp. 214–220, 1960.

[11] Y. Q. Wang, L. A. Penner, and S. J. Ormiston, "Analysis of laminar forced convection of air for crossflow in banks of staggered tubes," *Numerical Heat Transfer*, vol. 38, pp. 819–845, 2000. https://doi.org/10.1080/104077800457449

[12] A. Dahiya, M. Amer, U. Sajjad, P. Borah, S. S. Sehgal, and H. Singh, "An experimental study on microchannel heat sink via different manifold arrangements," *SN Applied Sciences*, vol. 2, 116, 2020. https://doi.org/10.1007/s42452-019-1784-6