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Forced Convection Heat Transfer over a Plate through Multi Nozzle

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ABSTRACT

A nozzle is a mechanical device or orifice designed to control the characteristics of a fluid flow as it exits an enclosed chamber or pipe. This paper is related with an Experimental study of forced convection heat transfer over flat plate through multi-nozzle, and study of parameters that affect the convective heat transfer. An experiment is conducted to study the effect of multi nozzle diameter, heat flux and speed of fan on the forced convection heat transfer in cooling of electronic components. Speed of fan is varied between 1.29 m/s to 4.47 m/s and nozzle diameter 4 mm to 6 mm with chamfer at constant nozzle-to test plate surface spacing. Multi nozzle array is more efficient than the direct fan cooling, because it increases the speed of fluid on heat plate target. Numerical study is done by using CFD and to study flow over plate with micro multi-nozzle zone during forced convection heat transfer by Simulation.

***Keywords*— a** Forced convection, Heat transfer, Nusselt number, Multiple nozzle, Parameters study.

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I. INTRODUCTION

a Cooling of electronic components has become a subject of interest in recent years present electronic components get overheated due to increased capacity, smaller size and less time for heat dissipation. Direct cooling using multiple jet impingements is considered as one of the effective method of cooling. Lately, micro multi-nozzle is used in evaporative cooling of electronic components to enhance forced convection heat transfer. A number of experimental and theoretical studies have been conducted to understand the physics of the heat transfer due to impinging jets over a flat plate. Impinging air or water jet cooling techniques is very useful for many other applications like drying of papers and films, tempering of glass and metal during processing, cooling of gas turbine surfaces, and cooling of electronic components. In many industrial applications, such as in cooling of electronics or internal cooling of turbine blade/vane surfaces, the jet outflow is often confined between the target surface and an opposing surface in which the jet orifice is located. Several researches (Lai et al. [1], Schroeder et al. [2], Victor et al. [3], Lee [4], Goldstein [5], Murthy [6] etc.), has focused on the heat transfer and fluid mechanics in free impinging jets, primarily in the turbulent regime. In micro-electronics cooling, air velocities are often limited by acoustic concerns and, hence, impinging jet heat transfer in the turbulent regime may be impractical. From both a fundamental and practical perspective it is important to study both the laminar and turbulent regimes are relevant for investigation. The confined impinging jet provides a practical solution to the microelectronics cooling problem because of the concentration of intense cooling over small areas. In previous studies that deal with study of various parameters Lee et al. [4] and Terzis [7] studied effect of diameter of nozzle/jet and concluded that varying jet diameter in the range of ±10%, has no detrimental effects on the area averaged Nusselt numbers for the target plate and the sidewalls. On the other hand, increasing jet diameters shows the best heat transfer capabilities for the impingement plate as in Anwarullahet al. [8] studied effect of distance between test plate and nozzle/jet and stated that Temperature gradient is higher at larger values of Reynolds number & lower values of H/d ratio. It is important to maintain proper distance between the component & nozzle for best performance, Murthy ([6],[9]) studied effect of no. of nozzles/jets, pitch between two nozzle, Mhetras [10] studied effect of no flow rate, type of nozzle, etc., affects the heat transfer and they conclude the effects of all these parameters decrease when the jet diameter is increased.

II. NUMERICAL STUDY

a Numerical study is performed to design the nozzle plate as well as to do validation of experimental work.

A. Cad model of plate

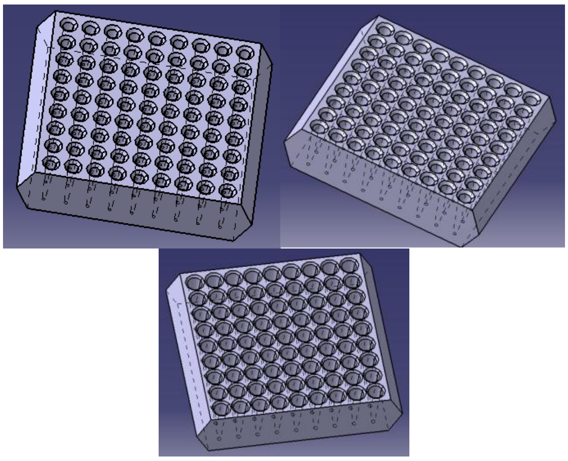


Fig.1. Cad model of Nozzle plate I, II, III.

B. Nozzle plate design

Size of Nozzle plate is 70mm X 80mm X 20mm as shown in Fig.2 and Nozzle plate is manufactured using ABS material by 3D printing as shown in Fig.3.

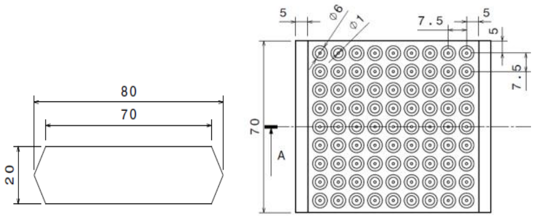


Fig.2.Dimension of Nozzle plate.

Fig.3.Fabricated Nozzle plate-I

C. Numerical analysis of Nozzle plate by using ANSYS

During Numerical analysisfour turbulence models are used for comparison. Velocity and Pressure contours are given below Fig.4 of Real *k-ε* and Fig.5 of RNG *k-ε*.

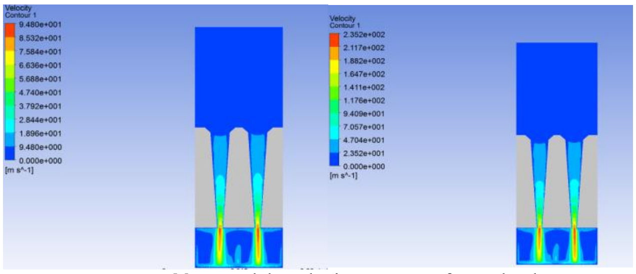


Fig.4.a. TI- Real k-ε Model, Velocity contour of Nozzle plate-I at V=3.2m/s and V= 1.29m/s.

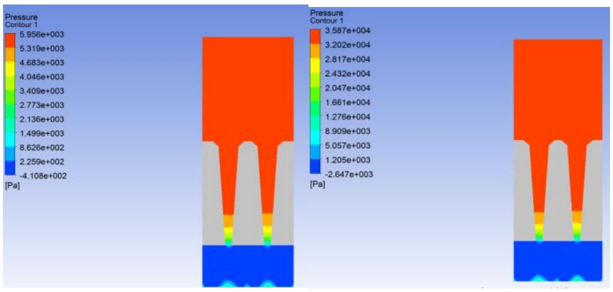


Fig.4.b. TI- Real k-ε Model, Pressure contour of Nozzle plate-I at V=3.2m/s and V= 1.29m/s.

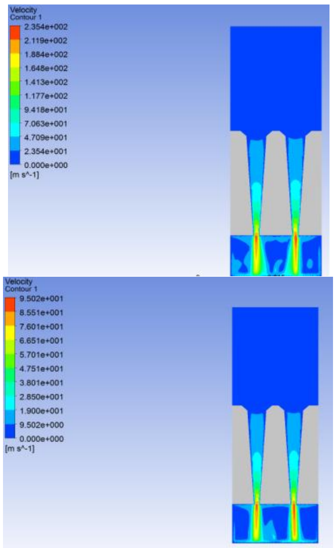


Fig.5.a. TI- RNG k-ε Model, Velocity contour of Nozzle plate-I at V=3.2m/s and V= 1.29m/s.

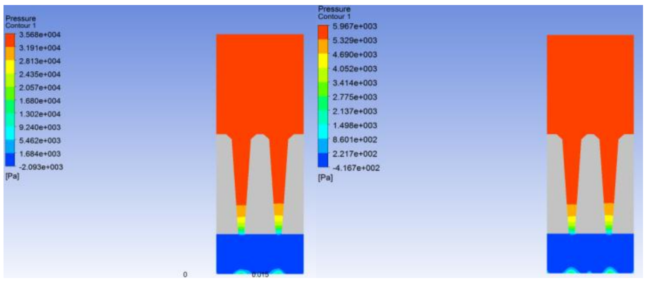


Fig.5.b. TI- RNG k-ε Model, Pressure contour of Nozzle plate-I at V=3.2m/s and V= 1.29m/s.

III.EXPERIMENTAL STUDY

a An experiment is conducted to study the effect of multi nozzle diameter, heat flux and speed of fan on the forced convection heat transfer in cooling of electronic components. Speed of fan is varied between 1.29 m/s to 4.47 m/s and nozzle diameter 4 mm to 6 mm with chamfer at constant nozzle-to test plate surface spacing. Reynold Number range is from 6609 to 24080. A schematic diagram of the experimental setup is shown in Fig. 6. In the experimental system, the important components are CPU Fan, Nozzle plate, Mild steel test plate and control panel. The control panel consists of voltmeter, ammeter, heater control, and temperature display unit. A 60 W copper heater plate, insulated on all sides by wooden frame, is used to heat the 60mm X 60mm X 5 mm mild steel test plate.Teflon coated four K- type thermocouples are used to measure the surface temperatures of the test plate. One thermocouple leads is attached to the copper heater plate. One thermocouple is used to measure the temperature of the air at inlet and two at outlet of duct. All the eight thermocouples are connected to a temperature display unit to observe the readings.

D. Mathematical Relations

To calculate Power supplied to heater is calculated by using eq. no. 1.

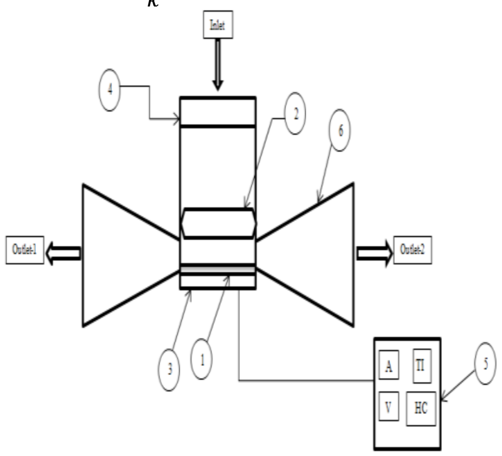
$$P = V \times I \qquad (1)$$

The electrical power consumed by the heater is dissipated through the plate by conduction. The total heat transfer from the plate can be written as eq. no. 2. Heat transfer coefficient of convection and dimensionless Nusselt no is calculated by using eq. no.3 and 4.

$$q_{total} = q_{conv} + q_{cond} + q_{rad} \qquad (2)$$

$$h = \frac{q_{conv}}{T_s - T_a} \qquad (3)$$

$$N_u = \frac{hD}{k} \qquad (4)$$



1. Test plate
2. Nozzle plate
3. Heater
4. CPU fan
5. Control panel
6. Convergent duct

IV. RESULT & DISCUSSION

a Design of experiment and numerical analysis for nozzle plate is completed.

The value of heat transfer coefficient without nozzle plate is 267 W/m^2.

A. Flow through Nozzle plate -Velocity contour

The result of Numerical analysis (by using ANSYS Fluent 15.0) shows that, Re values RNG k-ε model are higher for all above mentioned nozzle plate I, II, III.Re values from RMS model are higher but Re fromk-ω model are lowerthan the experimental values. Therefore, it can be concluded that RNG k-ε model is the appropriate model to be used in this study. The discrepancy between the Re from different turbulence models can be attributed to the difference in the structure of the turbulent intensity (TI). The results show that k-ε model gives the highest values of turbulence intensity compared to RSM and RNG k-ε model respectively and the peak value appeared at the stagnation point for k-ε model moved away in radial direction for RSM and even further for RNG k-ε model.

Correlations for Nusselt number in liquid impingement jet systems are shown in Table-II and Studies of heat transfer done using liquid impingement jet are shown in Table-III.

TABLE.I
COMPARISON OF CFD TURBULENCE MODELS USED FOR NOZZLE ANALYSIS

Turbulence Model	Computational Cost (hours)	Re prediction Error
k-ε	Moderate (7.5)	Good
RNG k-ε	Moderate(6)	Excellent
k-ω	Low (10)	Poor
SST	High(17)	Poor

V.CONCLUSIONS

a This paper is useful to find out correlations related to forced convection heat transfer over plate through jets/nozzles at various values of Reynolds number. Due to use of Nozzle plate, heat transfer rate may increase. Numerical study of Flow through Nozzle plate shows we get higher accuracy with RNG k-ε- Turbulent model.

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