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Numerical Study on Effect of Nozzle Size for Jet Impingement Cooling with Water-Al_2O_3 Nanofluid

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Abstract: ***A numerical model is developed using ANSYS Fluent software so as to study the effect of nozzle size for jet impingement cooling with water-Al_2O_3 nanofluid. The conservation equations of continuity, momentum and energy are solved to predict the heat transfer behaviors. Numerical simulations are performed with water-Al_2O_3 nanofluid jets for predicting temperature fields over the target plate by considering jet velocity of 60 m/s and nozzle to target plate distance of 5 mm along with four different nozzle diameters of 1, 2, 3 and 4 mm. As anticipated from each temperature field, temperature slowly increases from jet striking point on the target plate towards radially outward direction. It might be owing to carrying of heat by water-Al_2O_3 nanofluid in the stated direction. The trends of temperature variations along the radial direction for the stated four different cases are very similar. However, the maximum temperatures associated with the target plate for the cases with nozzle diameters of 1, 2, 3 and 4 mm are observed to be 320, 310, 307 and 308 K, respectively. Hence, nozzle diameter of 3 mm pertains to relatively lower maximum temperature of 307 K over the target plate. Thus, the stated case is the optimum one.***

Index Terms: ***Numerical Study, Nozzle Size, Jet Impingement Cooling, Water-Al_2O_3 Nanofluid.***

I. INTRODUCTION

The impinging jets have got several uses for instance in paper dehydrating, fabric processing, vehicle manufacturing, sheet metal quenching, electronics cooling, etc. The orthodox cooling techniques as deployed heretofore for example free and forced convection of air is not suitable for the high heat flux usages. However, in the last few years the unconventional method of cooling that has caught and driven the investigators' around the world is the habit of liquid jet impingement cooling. Moreover, nanofluid cooling is straightforwardly vital since air cooling is deficient to provide the get-up-and-go. Experimental exploration and theoretical inspection of thermal distribution over flat plate because of air jet impingement is described in the literature [1]. Computational model with simulating assessments are amply eye-catching in sorts [2-15]. Impinging slot jet over an annulus exterior is very well described [16]. Despite the fact that the liquid jet impingement cooling evades the challenges vis-à-vis the high thermal resistance related with the air cooling, on the other hand, the usage of nanofluid as coolant for impinging jet is the key motivation of the present research. In this study, the thermal performances of impinging jet with water-Al_2O_3 nanofluid as coolant are investigated numerically. Furthermore, the present numerical study relates to the effect of nozzle size on jet impingement cooling with water-Al_2O_3 nanofluid.

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II. ELUCIDATION OF PHYSICAL MODEL

Figure 1 exhibits the physical model flow domain which comprises a heated target plate demonstrating the bottom wall, a nozzle with velocity inlet at the middle/center of the top wall and two vertical/side walls indicated by the outflow boundary condition with the exit pressure corresponding to the ambient pressure.

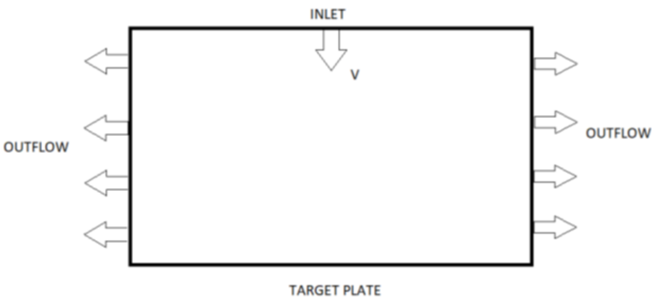

Figure 1. Physical model flow domain

III. NUMERICAL METHODOLOGY

Figure 2 demonstrates the ANSYS Workbench concerning the Fluent Module as the Interface that is intended for solving the above mentioned physical model problem. With the aim of getting the simulation predictions the mandatory steps like making geometry and domain, meshing and then the desired solution method are initialized to execute the simulation wherein the conservation equations (as described underneath in the form of equations 1-4) of mass, momentum and energy alongside the boundary conditions are chosen using ANSYS Fluent software. System of linear equations are solved by the Solver. Once the iterations progress, ANSYS Fluent creates the contours and curves with which several plots can be drawn to associate the numerical predictions with the projections. Through the post processing the predictions are thoroughly analyzed for getting numerous insights.

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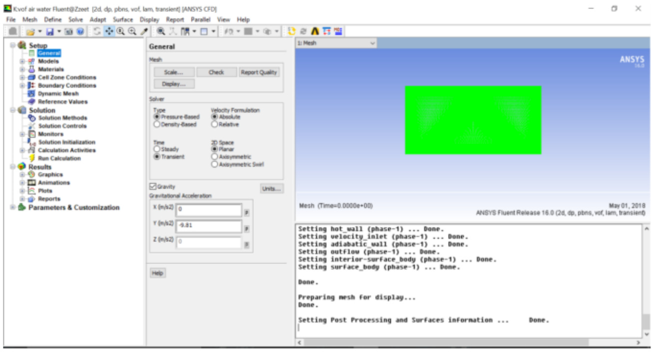

Figure 2. Flow domain within ANSYS Fluent interface

Continuity:
$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

X-momentum:
$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \quad (2)$$

Y-momentum:
$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\rho g \quad (3)$$

Energy:
$$\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

In the present investigation, several simulations are accomplished through water-Al_2O_3 nanofluid jets. The jet velocity of 60 m/s and the nozzle to heated target plate distance of 5 mm together with four different nozzle diameters of 1, 2, 3 and 4 mm are considered for predicting the thermal behaviors through ANSYS Fluent software. The governing transport equations of continuity, momentum and energy relating to the forced convection are solved to predict the heat transfer behaviors. The time step chosen during the entire simulation is 0.0001 seconds.

In addition, the thermo-physical properties of the Al_2O_3 nanoparticles considered in the present investigation and the ambient condition taken for the present system simulations, are also summarized in under-mentioned Table 1.

Table 1. Thermophysical properties and ambient data.

Nanoparticle Properties	Al_2O_3
Density, ρ (Kg/m^3)	3970
Specific heat, C_P (J/kg-K)	765
Thermal conductivity, k (W/m-K)	36
Ambient air temperature	300 K

IV. RESULTS AND DISCUSSION

Effect of Nozzle Size on Cooling Behavior

Numerical simulations are performed with water-Al_2O_3 nanofluid jets for predicting the effect of nozzle size on heat transfer behaviors over the target plate by considering the jet velocity of 60 m/s and the nozzle to target plate distance of 5 mm along with four different nozzle diameters of 1, 2, 3 and 4 mm.

A. Case Study with Nozzle Diameter of 1 mm

Figure 3 demonstrates the colored temperature field (along with the colored horizontal bar) over the target plate associated with the nozzle diameter of 1 mm. As anticipated, the temperature slowly increases from the jet striking point on the target plate towards the radially outward direction. Furthermore, the predicted temperature varies from 300 K (at the jet striking point) to 320 K (in the far field) over the target plate. It might be owing to the taking away of heat by water-Al_2O_3 nanofluid in the stated direction.

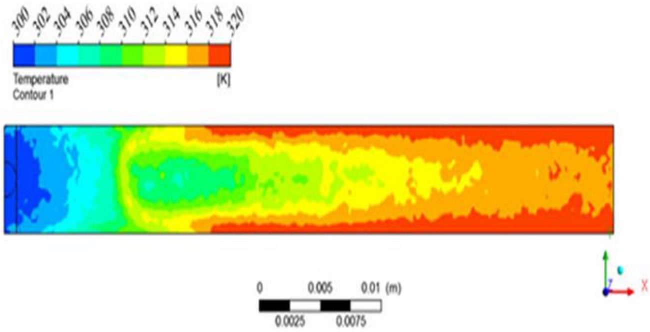

Figure 3. Temperature field for nozzle diameter of 1 mm

B. Case Study with Nozzle Diameter of 2 mm

Figure 4 demonstrates the colored temperature field (along with the colored horizontal bar) over the target plate associated with the nozzle diameter of 2 mm. As observed, the temperature field appears to be symmetric because of the normal jet impingement. As anticipated, the temperature slowly increases from the jet striking point on the target plate towards the radially outward direction. Furthermore, the predicted temperature varies from 300 K (at the jet striking point) to 310 K (in the far field) over the target plate. It might be owing to the taking away of heat by water-Al_2O_3 nanofluid in the stated direction. In addition, the appearance of hump-like shape within the temperature field might be because of the presence of minor turbulence along the flow.

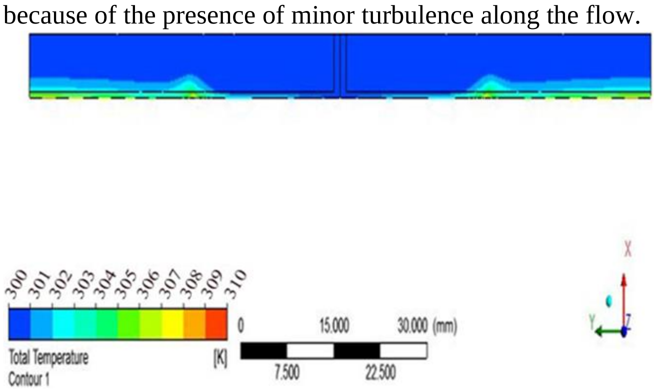

Figure 4. Temperature field for nozzle diameter of 2 mm

C. Case Study with Nozzle Diameter of 3 mm

Figure 5 demonstrates the colored temperature field (along with the colored horizontal bar) over the target plate associated with the nozzle diameter of 3 mm. As anticipated, the temperature slowly increases from the jet striking point on the target plate towards the radially outward direction. Furthermore, the predicted temperature varies from 300 K (at the jet striking point) to 307 K (in the far field) over the target plate.

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It might be owing to the taking away of heat by water-Al_2O_3 nanofluid in the stated direction.

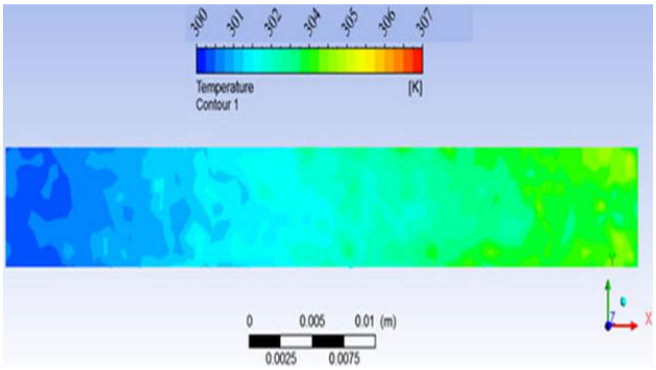

Figure 5. Temperature field for nozzle diameter of 3 mm

D. Case Study with Nozzle Diameter of 4 mm

Figure 6 demonstrates the colored temperature field (along with the colored horizontal bar) over the target plate associated with the nozzle diameter of 4 mm. As anticipated, the temperature slowly increases from the jet striking point on the target plate towards the radially outward direction. Furthermore, the predicted temperature varies from 300 K (at the jet striking point) to 308 K (in the far field) over the target plate. It might be owing to the taking away of heat by water-Al_2O_3 nanofluid in the stated direction.

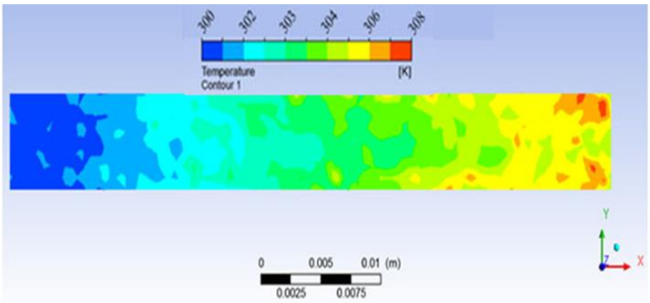

Figure 6. Temperature field for nozzle diameter of 4 mm

Comparison of Case Studies with Different Nozzle Diameters

Figure 7 demonstrates the comparative plots concerning temperature versus radial distance for four different cases with nozzle diameters of 1, 2, 3 and 4 mm. The trends of temperature variations along the radial direction for the stated cases are very similar. However, the maximum temperatures associated with the target plate for the cases with nozzle diameters of 1, 2, 3 and 4 mm are observed to be 320, 310, 307 and 308 K, respectively. Hence, the case with nozzle diameter of 3 mm pertains to relatively lower average temperature and thus, this case (of 3 mm diameter) is the optimum one.

In addition, the stated cases are further highlighted in Table 2 together with figure 8. Both show the variation in maximum temperature over the target plate with the variation in nozzle size. Again it puts aside the same optimal case of 3 mm nozzle diameter which corresponds to the optimal maximum temperature of 307 K over the target plate as is obvious from the stated table/figure.

Table 2. Nozzle size with maximum temperature over target plate.

Nozzle size (mm)	Maximum Temperature (ºK)
1	320
2	310
3	307
4	308

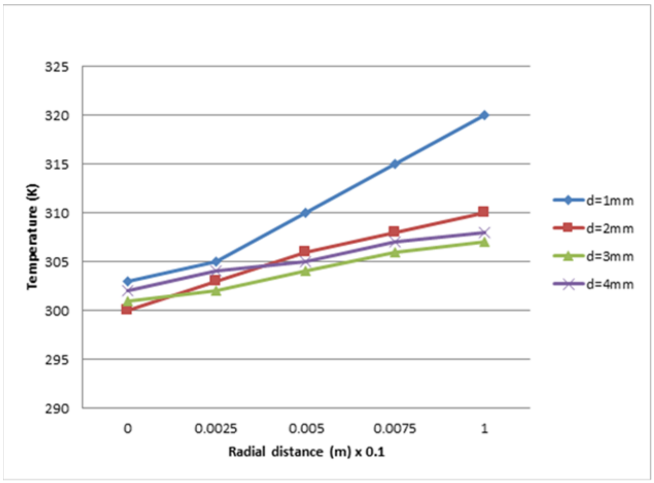

Figure 7. Temperature vs. Radial distance

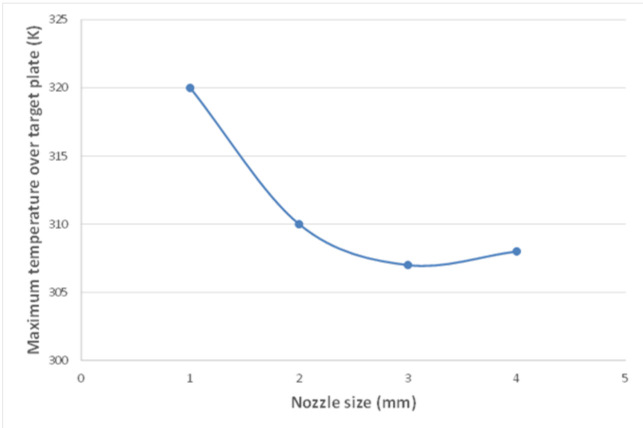

Figure 8. Nozzle size vs. maximum temperature over target plate

V. CONCLUSION

The present study pertains to the effect of nozzle size for jet impingement cooling with water-Al_2O_3 nanofluid. A numerical model is developed using ANSYS Fluent for solving the conservation equations of continuity, momentum and energy in order to predict the heat transfer behaviors. Numerical simulations are conducted with water-Al_2O_3 nanofluid jets for predicting the thermal performances over the target plate by considering the jet velocity of 60 m/s and the nozzle to target plate distance of 5 mm along with four different nozzle diameters of 1, 2, 3 and 4 mm.

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As observed from each temperature field, the temperature slowly increases from the jet striking point on the target plate towards the radially outward direction. It may be as a result of the taking away of heat by water-Al_2O_3 nanofluid in the said direction. The natures of temperature variations along the radial direction for the said four different cases are very comparable. But, the maximum temperatures over the target plate for the cases with nozzle diameters of 1, 2, 3 and 4 mm are predicted to be 320, 310, 307 and 308 K, respectively. Therefore, as observed, the case with nozzle diameter of 3 mm involves comparatively lower maximum temperature of 307 K over the target plate. That's why, the case with 3 mm nozzle diameter is the ideal one.

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Dr. N. K. Kund has obtained both M.Tech. & Ph.D. in Mechanical Engineering from Indian Institute of Science Bangalore. He has also obtained B.Tech.(Hons) in Mechanical Engineering from IGIT Sarang, Utkal University Bhubaneswar. He has published several research papers in international journals and also guided many research scholars, besides, wide teaching and research experience. He is presently working as Associate Professor in the Department of Production Engineering, VSSUT Burla (A Government Technical University).

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