Comparative CFD Studies on Jet Impingement Cooling Using Water and Water-Al_2O_3 Nanofluid as Coolants

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Abstract: ***The present study involves numerical investigations on jet impingement cooling with the water-Al_2O_3 nanofluid as coolant. A series of numerical simulations along with the CFD studies are carried out using ANSYS Fluent software. The appropriate governing transport equations of continuity, momentum and energy relating to the forced convection are solved to predict the velocity, temperature and the pressure fields. The hydrodynamic modelling involves the inertia, viscous and the pressure forces concerning the velocity and pressure. However, the thermal modelling relates to the convection and diffusion concerning only the temperature. Normally, the target plate cooling also involves the identified model parameters such as the jet velocity, nozzle diameter and the nozzle to heated target plate distance. The numerical simulations are performed with the jet velocity of 60 m/s, nozzle diameter of 2 mm and the nozzle to heated target plate distance of 5 mm so as to predict the flow behaviors. As expected, the pressure slowly decreases and the velocity together with the temperature gradually increases along the radially outward direction over the heated target plate from the stagnation point. In addition, the numerical simulations are also carried out only with the water in order to compare the cooling behavior with the water-Al_2O_3 nanofluid. Though, the trends of results are very similar for both water as well as water-Al_2O_3 nanofluid, however, the later one gives the superior cooling effect.***

Index Terms: ***CFD, Coolant, Jet Impingement, Temperature, Water-Al_2O_3 Nanofluid.***

I. INTRODUCTION

The conventional cooling practices as employed previously for instance free as well as forced convection of air is no longer acceptable for the high heat flux uses. Even, in the recent years the alternative form of cooling which has apprehended and motivated the researchers' around the world is the usage of liquid jet impingement. Even though, it circumvents the issues relating to the high thermal resistance associated with the air cooling, however, the use of nanofluid as coolant for impinging jet is the prime focus of the present study.

Furthermore, nanofluid cooling is truly vital as air cooling is lacking to support the get-up-and-go. Experimental investigation and theoretical examination of thermal distribution over horizontal plate owing to air jet impingement is reported in the text [1]. Numerical model with simulating appraisals are sizably conspicuous in sorts [2-17]. Impinging slot jet over an annulus surface is well shaped [18].

In this paper, both thermal and fluid flow behaviors of impinging jet using water-Al_2O_3 nanofluid as coolant are studied numerically. In addition, the predicted thermal behaviors of impinging jets with water (alone) and water-Al_2O_3 nanofluid are compared.

II. ILLUSTRATION OF PHYSICAL MODEL

Figure 1 demonstrates the physical model involving a two dimensional rectangular domain which includes a heated target plate representing the bottom wall, a nozzle with velocity inlet at the middle/center of the top wall and two vertical/side walls represented by the outflow boundary condition with the exit pressure corresponding to the atmospheric pressure.

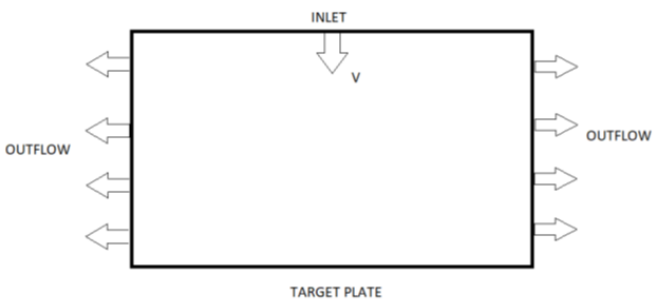

Fig. 1. Illustration of Physical flow domain

III. NUMERICAL METHOD

Figure 2 represents the ANSYS Workbench involving the Fluent Module as the Interface which is used for solving the present physical model/problem. In order to get the simulation predictions the basic steps like creating geometry/domain, meshing and then the specific solution method are initialized to run the simulation in which the governing transport equations of mass, momentum and energy (as described from equations 1 to 4) together with the boundary conditions are given using ANSYS Fluent software. The primary task of the Solver is to solve the system of linear equations. When the iterations start, ANSYS Fluent generates the contours/curves using which numerous plots can be drawn to compare the predicted output with the expected results. With the post processing the results are very well analyzed for finding several parameters.

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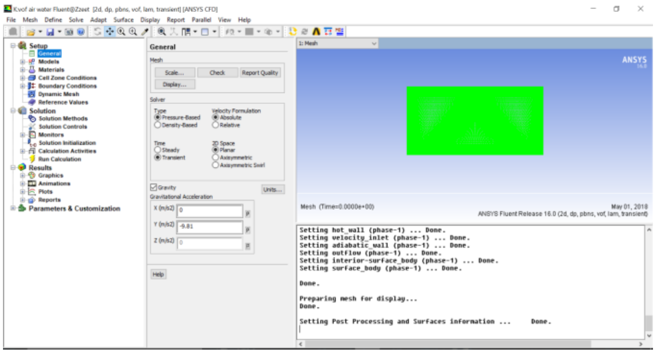

Fig. 2. Flow domain within ANSYS Fluent interface

Continuity: $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$ (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 research, numerous CFD simulations are performed with the jet velocity of 60 m/s, nozzle diameter of 2 mm and the nozzle to heated target plate distance of 5 mm with the aim of predicting the flow performances using ANSYS Fluent software. The governing transport equations of continuity, momentum and energy pertaining to the forced convection are solved to predict the velocity, temperature and the pressure fields. The time step taken in the simulation is 0.0001 seconds.

Besides, the thermo-physical characteristics of the Al_2O_3 nanoparticles chosen in the current examination and the ambient condition taken for the current 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

A. Using Water-Al_2O_3 Nanofluid as Coolant

A series of CFD simulations are accomplished with the jet velocity of 60 m/s, nozzle diameter of 2 mm and the nozzle to target plate distance of 5 mm with the aim of predicting the hydrodynamic and thermal flow behaviors.

Velocity field

Figure 3 demonstrates the velocity field relating to the jet impingement cooling with the water-Al_2O_3 nanofluid as coolant. Evidently, the velocity flow field appears to be symmetric due to the normal jet impingement. As anticipated from the horizontal coloured bar, the velocity progressively increases when moving along the radially outward direction over the heated target plate from the stagnation point. It may be due to the predominance of the inertia effect. Again in the far field i.e. after certain distance from the stagnation point, the velocity starts decreasing because the viscous effect becomes predominant. The presence of hump-like shape within the velocity flow field is mainly owing to the existence of minor turbulence along the flow that may slightly alter the nature of flow. Owing to the turbulence the flow develops additional velocity; while the jet velocity is 60 m/s, the simulation shows maximum velocity of 67 m/s.

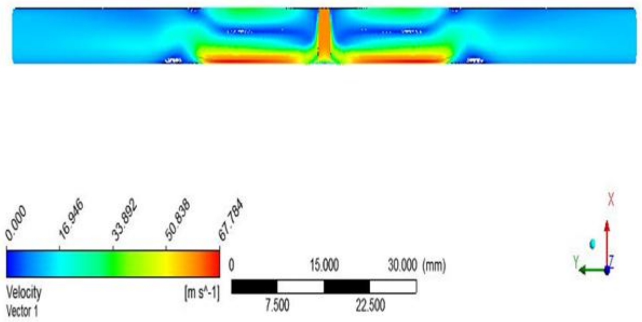

Fig. 3. Velocity field

Temperature field

Figure 4 exhibits the temperature field pertaining to the jet impingement cooling with the water-Al_2O_3 nanofluid as coolant. Obviously, the temperature flow field seems to be symmetric owing to the normal jet impingement. As expected from the horizontal coloured bar, the temperature gradually increases when moving along the radially outward direction over the heated target plate from the stagnation point. It may be because of the carrying away of the heat by the Al_2O_3 nanofluid from the stagnation point along the radially outward direction. The occurrence of hump-like shape within the temperature flow field is mostly due to the appearance of minor turbulence along the flow that may somewhat change the nature of flow.

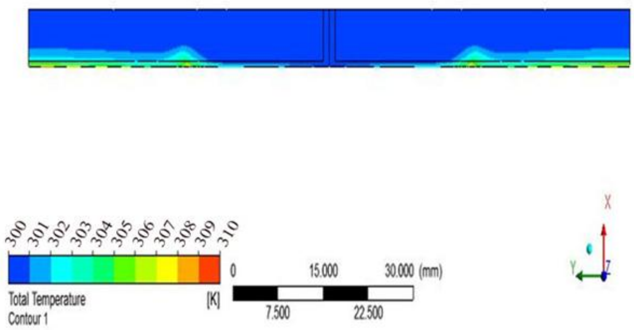

Fig. 4. Temperature field

In addition, over the target plate, the predicted temperature varies from 310 K near the edge to 300 K at the stagnation point. In other words, the predicted temperature ranges from 300 K to 310 K with the average temperature of 305 K which is very close to the ambient temperature.

Pressure field

Figure 5 illustrates the pressure field relating to the jet impingement cooling with the water-Al_2O_3 nanofluid as coolant. Certainly, the pressure flow field appears to be symmetric due to the normal jet impingement. As anticipated from the horizontal coloured bar, the pressure progressively drops when moving along the radially outward direction over the heated target plate from the stagnation point. It may be caused by the prevalence of the inertia effect. The existence of wakes within the pressure flow field is primarily as a result of the occurrence of minor turbulence that may marginally change the nature of flow. The pressure field is investigated in order to detect pressure drop along the flow because the pressure drop within the flow field may cause uneven heat transfer and the target plate may not experience constant temperature gradient. Over the target plate, the predicted pressure varies from -10 bar within the wake to 13 bar at the stagnation point.

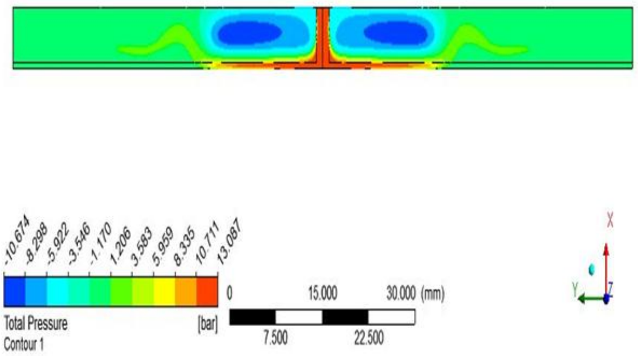

Fig. 5. Pressure field

B. Using Water as Coolant

Figure 6 shows the temperature field concerning the jet impingement cooling with only water as the coolant. Obviously, the temperature flow field seems to be symmetric owing to the normal jet impingement. The trends of results are very similar to the case with water-Al_2O_3 nanofluid as coolant. However, over the target plate, the predicted temperature varies from 335 K adjoining the edge to 305 K at the stagnation point. In other words, the predicted temperature varies from 305 K to 335 K with the average temperature of 320 K which is quite above the ambient temperature.

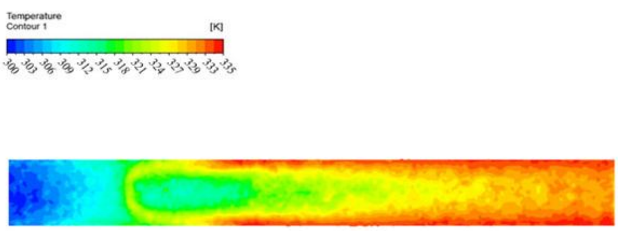

Fig. 6. Temperature field

C. Comparison of Water and Water-Al_2O_3 Nanofluid as Coolants

Figure 7 compares the predicted heat transfer performances of impinging jets with water (alone) and water-Al_2O_3 nanofluid as coolants. Though, the trends of results are really analogous for both water and water-Al_2O_3 nanofluid, however, the later one (i.e. water-Al_2O_3 nanofluid) offers quite higher cooling effect. It may be attributable to the enhanced thermal conductivity of the water-Al_2O_3 nanofluid. Thus, the temperature gradient over the target plate is relatively less for the case with the water-Al_2O_3 nanofluid as coolant. Therefore, the average temperatures of target plate using water (alone) and water-Al_2O_3 nanofluid (as coolants) are predicted to be 320 K and 305 K respectively.

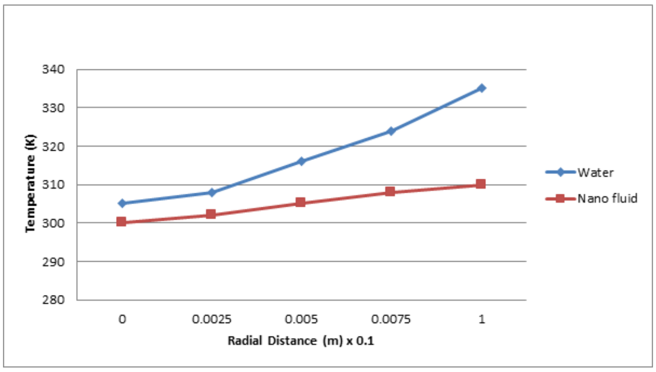

Fig. 7. Temperature profile with water and water-Al_2O_3 nanofluid as coolants

V. CONCLUSION

In this research, both thermal and fluid flow behaviours of impinging jet using water-Al_2O_3 nanofluid as coolant are investigated numerically. CFD simulations are performed using ANSYS Fluent software. The conservation equations of mass, momentum and energy pertaining to the forced convection are solved to foresee the velocity, temperature and the pressure fields. The fluid flow modelling includes the inertia, viscous and the pressure terms vis-à-vis the velocity and pressure. But, the thermal modelling includes the convection and diffusion vis-à-vis only the temperature. The identified model parameters are the jet velocity, nozzle diameter and the nozzle to heated target plate distance. The CFD simulations are carried out using the jet velocity of 60 m/s, nozzle diameter of 2 mm and the nozzle to heated target plate distance of 5 mm intended to foresee the flow performances. Of course, the pressure gently decreases and the velocity alongside the temperature progressively increases along the radially outward direction over the target plate from the stagnation point. Besides, the numerical simulations are also performed with water only. Furthermore, the predicted thermal behaviours of impinging jets with water (alone) and water-Al_2O_3 nanofluid are compared. Though, the nature of results are alike for both the stated fluids, however, the water-Al_2O_3 nanofluid is observed to give better cooling effort.

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