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ORIGINAL ARTICLE

Numerical investigation for heat transfer enhancement using nanofluids over ribbed confined one-end closed flat-plate

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Abstract Impinging jet is one of various methods of cooling with the ability to achieve high heat transfer rates and improve average surface's Nusselt number. This method has vast industrial applications including integrated use in solar collectors, gas turbine cooling, refrigeration, air conditioning and electronics cooling. A numerical study is conducted to study the effects of using nanofluids on impinging slot jet over a flat plate with a ribbed surface. The main objective of the study was to investigate the possibility of improving the overall heat transfer rate by focusing on the improvements in the local and average surface Nusselt number values. Several parameters effects are studied including Solid Volume Fraction, Richardson number and Reynolds number. These results indicated a marked improvement in average Nusselt number with the increase in the solid volume fraction. Also, there is an amended value when the buoyancy effect is dominant over the whole domain. The results are shown in the form of streamlines, isotherms and Nusselt numbers contra other variables. The current work was simulated using a FORTRAN CFD Code, which discretizes the non-dimensional forms of the governing equations utilizing the finite volume method and solving the consequent algebraic equations using Gauss-Seidel method Utilizing TDMA.

1. Introduction

Nanofluids have been one of the interests of researchers to enhance heat transfer rates in industrial thermal systems. Lower thermal conductivity is a primary limitation of a base fluid, while solid particles can increase thermal conductivity when dispersed in base fluid. There are two categories of nanofluids metallic and non-metallic based on the type of nanoparticles used such as $\mathbf{Al_2O_3}$, **Ag**, **CuO**, **Cu**, $\mathbf{SiO_2}$ and $\mathbf{TiO_2}$ [1]. Various heat transfer enhancement techniques were researched to increase local heat transfer coefficient. Recently, large enhancements of the thermal conductivity have been discovered in an impinging jet system. This system has proved to be one of the notable methods for enhancing heat transfer, where a jet is directed to impinge

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Nomenclature

A	area (m^2)
Al_2O_3	aluminium-oxide
Ag	silver
a	Rib's width (m)
b	Rib's height (m)
C_p	specific heat at constant pressure (J/kg·K)
CuO	copper oxide
Cu	copper
D	Rib's spacing (m)
Gr	Grashof number
H	plate height (m)
h	average heat transfer coefficient ($W/m^2 \cdot K$)
k	thermal conductivity (W/m·K)
L	plate length (m)
Nu	Nusselt number
Pr	Prandtl number
q	heat flux (W/m^2)
Re	Reynolds number
Ri	Richardson number
SiO_2	silicon dioxide
TiO_2	titanium dioxide
T	temperature (K)
u, v	velocity components in x, y direction respectively (m/s)
U, V	dimensionless velocity components in X, Y direction
W	slot jet width (m)
x, y, z	Cartesian coordinates
X, Y, Z	dimensionless Cartesian coordinates

Greek symbols

ρ	density (kg/m^3)
ϕ	solid volume fraction
β	thermal expansion coefficient (K^{-1})
μ	dynamic viscosity ($N \cdot s/m^2$)
v	kinematic viscosity (m^2/s)
θ	dimensionless temperature
α	thermal diffusivity (m^2/s)

Subscripts

bf	base fluid
eff	effective
j	jet
nf	nanofluid
p	particle
s	surface

Abbreviations

FVM	Finite Volume Method
SIMPLE	Semi-Implicit Method for Pressure Linked Equations
SIMPLER	Semi-Implicit Method for Pressure Linked Equations (Revised)
TDMA	Tri-Diagonal Matrix Algorithm

on a heated surface to cool it. However, when dealing with low thermal properties of working fluids i.e. air or water a less satisfying results are expected. Hence, a mixture of nanoparticles with one of those base fluids is expected to give a higher heat transfer rates [2].

Jet Impingement using nanofluid has been studied extensively numerically and experimentally. Li et al. [3] investigated both jet impingement and forced convection. He concentrated on the performance of nanofluids in a submerged configuration. The results show improvements in the heat transfer compared to pure water and presented correlations with agreement of experimental results. These correlations can calculate Nusselt numbers at given solid volume fraction, jet to plate spacing and Reynolds number. El-Maghlany et al. [4] numerically investigated the effects of nanofluid on the thermal performance of ribbed flat plate using cu-water nanofluid. Teamah et al. [5] numerically and experimentally investigated flow structure and heat transfer of jet cooling over flat plat utilizing nanofluids (Al_2O_3). The mathematical model was derived and numerically solved using Finite volume with SIMPLER algorithm. Manca et al. [6] numerically investigated confined slot jet using nanofluid and pure water for laminar steady state conditions, and comparison for various Reynolds Numbers, Solid Volume Fractions and Plate to jet spacing ratios was provided. Heshmati et al. [7] investigated mixed convection heat transfer characteristics numerically for the effect of nanofluid on a two dimensional backward facing step. The governing equations were solved using FVM with SIMPLE algorithm to link velocity and pressure fields for different Reynolds numbers. Dutta et al. [8] numerically investigated the behavior of hydrodynamic and heat transfer for Al_2O_3 – Water nanofluid for both laminar and turbulent confined slot jet. He studied the effect of solid volume fraction at 3 and 6% using a single phase fluid approach to model the nanofluid. Nguyen et al. [9] experimentally investigated the effects of temperature and solid volume fraction on dynamic viscosity for two different nanoparticle sizes. The data were collected from commercial viscometer piston type at room conditions up to 75 °C. Huang et al. [10] numerically investigated effect of Al_2O_3 – Water nanofluid on confined circular jet impinging for turbulent flow over a flat plate. The conditions were at constant wall temperature for different jet to plate spacing ratio, solid volume fraction and Reynolds number. He observed that a maximum of 10% is obtained when compared to performance using pure water at jet to plate spacing of 5. Singh et al. [11] experimentally investigated the effect of laminar nanofluid jet on a heated steel surface and compared it with water jet. The effects of concentration and jet's velocity for TiO_2 based nanofluid were evaluated experimentally. The results showed an enhancement compared to water results with an increase in the average heat transfer rate. Maïga et al. [12] investigated the hydrodynamic and thermal characteristics of laminar forced convection flow of nanofluid on two geometries using numerical simulation. The results clearly revealed that