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Enhancement heat transfer characteristics in the channel with Trapezoidal rib–groove using nanofluids

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ABSTRACT

Numerical study of heat transfer due to turbulent flow of nanofluids through rib–groove channel have been investigated. The continuity, momentum and energy equations are solved by the finite volume method (FVM). Four different rib–groove shapes have been examined. Four different types of nanoparticles, Al_2O_3, CuO, SiO_2, and ZnO with different volumes fractions in the range of 1–4% and different nanoparticle diameter in the range of 25–70 nm, have been also studied. The computations are performed under constant temperature over a range of Reynolds number (Re) 10,000–40,000. Results indicate that the Trapezoidal with increasing height in the flow direction rib–trapezoidal groove has the best heat transfer rate and high Nusselt number. It is also found that the SiO_2 – nanofluid has the highest value of Nusselt number in comparison with the other type of nanofluids. The Nusselt number increases as the volume fraction increases and it decreases as the nanoparticle diameter increases. The present study shows that these Trapezoidal rib–groove using nanofluids have the potential to dramatically increase heat transfer characteristics and thus can be good candidates for the development of efficient heat exchanger device.
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1. Introduction

There are many researchers who studied the forced convection heat transfer in a rib–groove channel. Recently, researchers have shown an increase in forced convection heat transfer. Attempts have been made to enhance heat transfer in the heat exchangers by using roughened surfaces such as rib, groove and helical rib in disturbing the flow and in providing transverse/longitudinal vortices or three dimensional mixing. There are many geometric shapes of the rib–groove channel which have been studied in the past. The common geometric shapes include rectangular, triangular, square, and circle. All these types of rib–groove channels were used in many engineering applications such as cross-flow heat exchanger, gas turbine airfoil cooling design, solar air heater blade cooling system, and gas cooled nuclear reactor.

One of the ways to enhance heat transfer in the separated regions is to employ nanofluids. Nanofluids are fluids that contain suspended nanoparticles such as metals and oxides. These nano-scale particles keep suspended in the base fluid.

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Nomenclature

A	Convection heat transfer area of rectangular channel, (m^2)
Al_2O_3	Aluminum Oxide
CuO	Copper Oxide
C_p	Specific heat at constant pressure, (J/Kg K)
D_h	Hydraulic diameter, m; [=4WH/2(W+H)]
d_p	Diameter of nanofluid particles, (nm)
d	Depth of grooved surface, (m)
e	Rib height, (m)
H	Channel Height, (m)
h	Convective heat transfer coefficient, (W/m^2 K)
H_2O	Water
k	Thermal conductivity of the fluid, (W/m K)
L	Length of channel, (m)
Nu	Nusselt number
q	Heat flux, (W/m^2)
Re	Reynolds number
SiO_2	Silicon dioxide
u	Velocity component at x-direction, (m/s)
v	Velocity component at y-direction, (m/s)
w	Width of rib–groove, (m)
W	Width of the channel, (m)
x	Distance along the x-coordinate, (m)
X	Distance along the non-dimensional x-co-ordinate, (x/W)
Y	Distance along the non-dimensional y-co-ordinate, (y/W)
ZnO	Zinc oxide

Greek Symbols

β	Modeling function
μ	Dynamic viscosity of the fluid, (Pa s)
ν	Kinematic viscosity of the fluid, (m^2/s)
ρ	Density of the fluid, (kg/m^2)
φ	Volume fraction, (%)
η	Thermal enhancement factor

Thus, it does not causes an increase in pressure drop in the flow field. Past studies showed that nanofluids exhibit enhanced thermal properties, such as higher thermal conductivity and convective heat transfer coefficients compared to the base fluid.

Kamali and Binesh [1] studied turbulent heat transfer and friction characteristics in a square duct with various-shaped ribs mounted on one wall. The simulations were performed for four rib shapes, i.e., square, triangular, Trapezoidal with decreasing height in the flow direction, and Trapezoidal with increasing height in the flow direction. The results shown the inter-rib distribution of the heat transfer coefficient were strongly affected by the rib shape and Trapezoidal ribs with decreasing height in the flow direction provide higher heat transfer enhancement and pressure drop than other shapes. Bilen et al. [2] presented an experimental study of surface heat transfer and friction characteristics of a fully developed turbulent air flow in different grooved tubes. Tests were performed for Reynolds number range 10,000–38,000 and for different geometric groove shapes (circular, Trapezoidal and rectangular). Among the grooved tubes, heat transfer enhancement was obtained up to 63% for circular groove, 58% for Trapezoidal groove and 47% for rectangular groove, in comparison with the smooth tube at the highest Reynolds number (Re=38,000).

Pingan et al. [3] employed standard $k-\varepsilon$ turbulence model and enhanced wall treatment to investigate the flow-field, heat transfer and resistance coefficient in two-dimensional channels with different ribs (rectangular/trapezoidal/triangular/semi circular cross section). Eiamsa-ard and Promvonge [4] performed the combined effects of rib–grooved turbulators on the turbulent forced convection heat transfer and friction characteristics in a rectangular duct under a uniform heat flux boundary condition (UHF). Promvonge and Thianpong assessed turbulent forced convection heat transfer and friction loss behaviors for air flow through a constant heat flux channel (CHF) fitted with different shaped ribs. The rib cross-sections used were triangular (isosceles), wedge (right-triangular) and rectangular shapes.

Jaurker et al. [5] presented the heat transfer and friction characteristics of rib-grooved artificial roughness on one broad heated wall of a large aspect ratio duct shows that Nusselt number can be further enhanced beyond that of ribbed duct while keeping the friction factor enhancement low. Manca et al. [6] presented a numerical investigation on air forced convection in a rectangular channel with constant heat flux applied on the bottom and upper external walls. Thinapong et al. [7] presented an experimental investigation on turbulent heat transfer and friction loss behaviors of airflow through a constant heat flux (CHF) channel fitted with different heights of triangular ribs.

Several investigations have been reported in the literature on the convective heat transfer in nanofluids; see, for example, Nguyen et al. [8] investigated experimentally the behavior and heat transfer enhancement of Al_2O_3/water nanofluid flowing inside a closed system that is used for cooling of micro-electronic components. For a 6.8 vol% concentration, the heat transfer coefficient was found to increase as much as 40% compared to that of the base fluid. Liu et al. [9] investigated the thermal conductivity of copper–water nanofluids produced by chemical reduction method. Results showed 23.8% improvement at 0.1% volume fraction of copper particles. Higher thermal conductivity and larger surface area of copper nanoparticles were attributed to this improvement. It was also noted that thermal conductivity increases with particles volume fraction but it decreases with the elapsed time. Mohammed et al. [10] investigated thermal and hydraulic characteristics of turbulent nanofluids flow in a rib–groove channel. The results indicated that the rectangular rib–triangular groove has the highest Nusselt number among other rib–groove shapes. The SiO_2 nanofluid has the highest Nusselt number compared with other nanofluid types. It was found that the Glycerin–SiO_2 shows the best heat transfer enhancement compared with other tested base fluids. Abed et al. [11] presented a numerical study of the heat transfer and flow characteristics in corrugated with V-shape lower plate using nanofluids. The computations are performed uniform

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