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Heat transfer behaviour of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow

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ABSTRACT

The CFD simulation of heat transfer characteristics of a nanofluid in a circular tube fitted with helical twist inserts under constant heat flux has been explained using Fluent version 6.3.26 in laminar flow. Al_2O_3 nanoparticles in water of 0.5%, 1.0% and 1.5% concentrations and helical twist inserts of twist ratios 2.93, 3.91 and 4.89 has been used for the simulation. All thermophysical properties of nanofluids are temperature dependent. The heat transfer enhancement increases with Reynolds number and decreases with twist ratio with maximum for the twist ratio 2.93. By comparing the heat transfer rates of water and nanofluids, the increase in Nusselt number is 5%–31% for different helical inserts and different volume concentrations. The maximum heat transfer enhancement is 31.29% for helical insert of twist ratio 2.93 and for the volume concentration of 1.5% corresponding to the Reynolds number of 2039. The data obtained by simulation match with the literature value of water with the discrepancy of less than $\pm 10\%$ for plain tube and tube fitted with helical tape inserts for Nusselt number.

1. Introduction

In the past decades, heat transfer enhancement technology has been developed and widely applied to heat exchanger applications; for example, refrigeration, automotives, process industry, chemical industry etc. To date, a large number of attempts have been made to reduce the size and costs of the heat exchangers. Also, heat transfer augmentation techniques play a vital role for laminar flow since the heat transfer coefficient is generally low in plain tubes. Many active and passive techniques are available for augmentation. Bergles [1,2] presented a comprehensive survey on heat transfer

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Nomenclature

C_{nf}	Specific heat of nanofluids
C_f	Specific heat of base fluid
C_p	Specific heat of nanoparticles
E	Energy component in energy equation
F	Force component in momentum equation, N
g	Acceleration due to gravity, m/s^2
k_{nf}	Thermal conductivity of nanofluids
k_{bf}	Thermal conductivity of base fluid
k_p	Thermal conductivity of nanoparticles
k_{eff}	Thermal conductivity in Energy equation, W/m K
K	Specific turbulent kinetic energy,
m	mass flow rate of fluid, kg/s
n	Shape factor of nanoparticles
NRe	Reynolds number based on internal diameter of the tube, dimensionless $NRe = D_i u \rho / \mu$
Nu	Nusselt number, dimensionless
p	Pressure component in momentum equation, N/m^2
S_m	Accumulation of mass, Kg
S_h	Accumulation of Energy, J
u_m	bulk average fluid velocity, m/s
u, v	Velocity component in momentum equation, m/s
Y	twist ratio (Length of one twist (360°)/ diameter of the twist), dimensionless

Greek symbols

φ	Volume fraction of nanofluids
μ_{nf}	Viscosity of nanofluids
μ_f	Viscosity of base fluid
μ_t	Turbulent viscosity or eddy viscosity, kg/m s
ρ_{nf}	Density of nanofluids
ρ_f	Density of base fluid
ρ_p	Density of nanoparticles
ρ	Density component in governing equations
τ	Stress component in momentum equation, N/m^2.

enhancement by various techniques. Among many techniques (both passive and active) investigated for augmentation of heat transfer rates inside circular tubes, tube fitted with full length twisted tape inserts using water (also called as swirl flow device) has been shown to be very effective, due to imparting of helical path to the flow. Also, good literature is available on convective heat transfer and CFD modeling of heat transfer augmentation process using swirl flow devices. Michiel Nijemeisland and Dixon [3] presented the comparison of CFD simulations to experiment for convective heat transfer in a gas–solid fixed bed. Hilde Vander Vyver et al. [4] reported the validation of CFD model of a three dimensional tube-in-tube heat exchanger. Modeling of heat transfer augmentation in a circular tube fitted with twisted tape inserts in a laminar flow using CFD was reported by Sivashanmugam et al. [5,6]. At higher heat flux conditions the conventional fluids are not capable of achieving the desired heat transfer rate and hence the research is underway to apply nanofluids in those environments. Choi [7] is the first who used the term nanofluids to refer to the fluids with suspended nanoparticles. Nanofluids are created by dispersing nanometer-sized particles (<100 nm) in a base fluid such as water, ethylene glycol or propylene glycol. Use of high thermal conductivity metallic nanoparticles like copper, aluminum, silver and silicon increases the thermal conductivity of such mixtures, thus enhancing their overall energy transport capability. Nanofluids because of their excellent thermal