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The heat transfer performances and entropy generation analysis of hybrid nanofluids in a flattened tube

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ABSTRACT

This article aims to study the heat transfer performances and the degree of thermodynamic irreversibility of two types of hybrid nanofluids, namely MWCNT + Fe_3O_4/water and ND + Fe_3O_4/water used in a flattened tube. The three-dimensional numerical analysis was performed for different working conditions as: Reynolds number (within the range 250–2000), volume concentration of hybrid nanoparticles (0–0.3%) and inlet temperatures (from 313 K to 333 K). The numerical results show that the use of hybrid nanofluids in flattened tubes enhances the heat transfer at all studied Reynolds numbers. The MWCNT + Fe_3O_4/water hybrid nanofluids exhibited higher enhancement in heat transfer compared to ND + Fe_3O_4/water hybrid nanofluids. In additions, the results indicate that the increase in volume concentration of hybrid nanoparticles leads to the decrease of the total entropy generation of MWCNT + Fe3O4/water and ND + Fe3O4/water hybrid nanofluids compared to base fluid. A reduction of entropy generation of 26.483% compared to the base fluid was obtained for 0.3 vol% MWCNT + Fe_3O_4 hybrid nanoparticles.

1. Introduction

Compact heat exchangers are widely used in industrial and automotive applications (automotive radiator, condensers and evaporators in air-conditioning, oil coolers, and intercoolers of compressors) due to high surface area per unit volume which leads to a higher efficiency than conventional heat exchangers. In order to improve the thermal performance of compact exchangers, various techniques were used to enhance heat transfer. The use of various surface geometries with surface argumentation of heat exchangers and the nanofluids are two different techniques to enhance thermal performance of highly efficient heat exchangers. The combination these techniques together leads to an increase in efficiency those heat exchangers.

In last decades, intensive studies were performed on heat transfer and flow characteristics of nanofluids in various configurations of heat exchangers, but studies concerning to the heat transfer and flow characteristics of nanofluids in flat tubes are yet limited.

The hybrid nanofluids are a new class of working fluids with enhanced thermo-physical properties which consists of two or more different solid particles into base fluid (water, ethylene glycol, water and ethylene glycol mixture). Studies concerning the measurement and modeling of thermo-physical properties (thermal conductivity and viscosity) of hybrid nanofluids are still limited compared with research in nanofluids. Some of the papers indicated that the thermal conductivities of hybrid nanofluids were higher than the thermal conductivities of nanofluids [1–6], in other studies were observed the thermal conductivities smaller than those of nanofluids [1,7], but there were studies which indicated the thermal conductivities between of thermal conductivities of the nanofluids which compose hybrid nanofluid [8,9]. Nevertheless, most of the studies in general indicated that the thermal conductivity of hybrid nanofluids increases with increasing concentration of hybrid nanoparticles and increasing temperature [2,3,5,10–15].

The thermal-hydraulic performances of automotive radiator using nanofluids were presented in two comprehensive reviews [16,17]. A numerical study concerning to heat transfer performances of the flat tubes of a automotive radiator using Al_2O_3 and CuO in ethylene glycol and water mixture (60:40) nanofluids was carried out by Vajjha et al. [18]. The simulations were performed in laminar flow to the Reynolds number within range 100–2000 and to volume concentrations of nanoparticles in the range 0–10% and 0–6% for Al_2O_3 and CuO respectively. They showed that the convective heat transfer coefficient, the local and the average friction factor and pressure loss increase with increasing volume concentration of nanoparticles added in the base fluid and the Reynolds number. Also, two correlations for Nusselt number were proposed by authors:

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Nomenclature

A_s	surface area, m^2	X	cartesian coordinates, m
C_f	skin friction coefficient	Z	axial distance from the inlet
c_p	specific heat, J/(kg K)		
D_h	hydraulic diameter, m	*Geek symbol*	
f	friction factor	ϕ	volume concentration
h	heat transfer coefficient, W/(m^2 K)	μ	dynamic viscosity, Pa s
H	height, m	ρ	density, kg/m^3
k	thermal conductivity, W/(m K)		
L	length, m	*Subscript*	
$\dot{m}$	mass flow rate, kg/s	ave	average
Nu	Nusselt number	b	bulk
P	pressure, Pa	bf	base fluid
Pr	Prandtl number	hnf	hybrid nanofluid
$\dot{Q}$	heat transfer rate, W	in	inlet
Re	Reynolds number,	nf	nanofluid
$\dot{S}_{gen}$	entropy generation, W/K	out	outlet
T	temperature, K	p	particle
U	velocity, m/s	s	surface
W	width, m		

$$Nu_{avg} = 1.9421\left(Re\,Pr\frac{D_h}{Z}\right)^{0.3} \text{for}\left(Re\,Pr\frac{D_h}{Z}\right) \geqslant 33.33 \quad (1)$$

$$Nu_{avg} = 6.1 + 0.003675\left(Re\,Pr\frac{D_h}{Z}\right)\text{for}\left(Re\,Pr\frac{D_h}{Z}\right) < 33.33 \quad (2)$$

The experimental study on heat transfer characteristics of ethylene glycol (EG) based copper (Cu) nanofluids used in an automotive radiator was performed by Leong et al. [19]. They noticed that the heat transfer enhancement was 3.8% for 2.0% Cu/EG nanofluids at a Re = 6000 (for air) and Re = 5000 (for nanofluid). Also, they observed a reduction of air frontal area of 18.7% when has been using nanofluids as coolant in car radiator and an increase of pumping power requirement of 12.13% compared with the base fluid.

Peyghambarzadeh et al. [20] performed a experimental study concerning the forced convection heat transfer in a automotive radiator using Al_2O_3/water, Al_2O_3/ethylene glycol and Al_2O_3/water + ethylene glycol (95:5, 90:10 and 80:20) as working fluids. The experiments were carried out to volume concentrations of nanoparticles in the range 0.1–1.0 vol%, at various volumetric flow rate (2–6 l/min) and at three inlet temperature 35, 45 and 50 °C. Experimental results showed that in different working fluid, the addition of a small amount of nanoparticles leads to a significant improvement in thermal performances of automotive radiator.

A numerical study of laminar flow and heat transfer characteristics of CuO/ethylene glycol nanofluids in a flattened tube was performed by Huminic and Huminic [21] for various volume concentrations of nanoparticles (0–4.0 vol%) and Reynolds numbers within the range 10–125. In this study, they were compared thermal performances of the flattened, elliptic and circular tubes and they concluded that the flattened tube exhibited better thermal performances by the use CuO/ethylene glycol nanofluids as working fluids.

Naraki et al. [22] experimental studied the thermal performances expressed by the overall heat transfer coefficient of CuO/water nanofluids in a automotive radiator and noticed an increases in overall heat transfer coefficient up to 8% at 0.4 vol% CuO/water compared with the distilled water.

Delavari and Hashemabadi [23] numerical investigated the heat transfer characteristics of Al_2O_3-water and Al_2O_3 ethylene glycol nanofluids through a flat tube under turbulent and laminar flows. The simulations were performed using single and two-phase approaches. In this paper, they showed that the Nusselt numbers using two-phase approach were higher than the results of the single phase, while insignificant differences in the friction factors were observed between the two models. The authors reported that the results of the two-phase model were 10–45% higher than for the single-phase model.

The heat transfer performance of automobile radiator using CNT and Al_2O_3 was performed by Chougule and Sahu [24] for concentrations of nanoparticles in the range of 0.15–1.0 vol% and volumetric flow rates of nanofluids within the range 2 l/min–5 l/min. In this study, the authors concluded that the CNT/water nanofluids exhibited significantly enhancement in heat transfer compared to the Al_2O_3/water nanofluids.

Another study concerning to the effects of tube flattening on the heat transfer performances of Al_2O_3–water nanofluid was numerical investigation by Safikhani and Abbassi [25]. All simulations were performed in laminar flow to an Reynolds number Re = 300 and to an volume concentration of nanoparticles of 5.0 vol% Al_2O_3 nanofluids and they found that increase of tube flattening leads to increase of the heat transfer and wall shear stress. In another study, Safikhani et al. [26] carried out study concerning multi-objective optimization of Al_2O_3/water nanofluid in a flat tube using various techniques as CFD (Computational Fluid Dynamics), ANN (Artificial Neural Networks) and NSGA II (Non-dominated Sorting Genetic Algorithms).

SiO_2/water and TiO_2/water nanofluids in a car radiator have been experimental and numerical investigation by Hussein et al. [27,28]. The results showed that the Nusselt number increase with both volume concentration of nanoparticles and volumetric flow rate for all cases studied. The maximum enhancement in Nusselt number was 30.06% and 25.12% for SiO_2/water and TiO_2/water nanofluids compared with the water.

Vajjha et al. [29] numerical studied heat transfer and flow characteristics of Al_2O_3/EG-W (60:40) and CuO/EG-W (60:40) with volume concentrations of nanoparticles within the range 0–6.0 vol% used in a flattened tube in turbulent flow. They found that the thermal performances of flat tube increase with increase both of volume concentration of nanoparticles and Reynolds number. Also, in this article, authors developed new correlations for the Nusselt number and the skin friction coefficient: