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Entropy Generation and Heat Transfer Rate for MHD Forced Convection of Nanoliquid in Presence of Viscous Dissipation Term

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ABSTRACT

In this paper, magnetohydrodynamic laminar forced convection of nanoliquid in a rectangular channel with an extended surface, top moving wall and three cylindrical blocks is numerically studied. The Lattice Boltzmann method is used for the resolution of the governing equations. Validity of the numerical home elaborated FORTRAN code was made and good agreement was found with published results. It is interspersed in this work by the effects of the following parameters: Reynolds number (50≤Re≤200), Hartmann number (0≤Ha≤50), nanoparticles volume fraction (0≤ϕ≤4%) and Eckert number (0.25≤Ec≤1). The numerical solution shows that the local and average Nusselt numbers ameliorate when the value of Reynolds number, Eckert number, and the nanoparticles volume fraction are enhanced. But decreases when the Hartmann number is increased. The impacts of viscous dissipation on heat transfer rate and entropy generation are more noticeable in the presence of a magnetic field. The addition of 4% of nanoparticles enhances the local Nusselt number by about 7%.

1. Introduction

The optimization of heat transfer is an objective to be achieved. Many researchers have been interested in this subject because of its importance in the industry. The addition of nanoparticles in conventional fluids is one solution among several to improve the heat transfer rate. This solution is called nanofluid, which was proposed for the first time by Choi *et al.,* [1] The experimental results show that the addition of nanoparticles enhances the thermal conductivity of fluids. The impacts of solid volume fraction and temperature on thermal conductivity of DWCNT- ZnO/water-ethylene glycol has been experimentally investigated by Mohammad *et al.,* [2]. The results disclosed that the

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thermal conductivity of nanofluid enhances with increasing concentration of nanoparticles. The influence of addition of Cu nanoparticles in base fluid on the thermal entropy generation and the frictional entropy generation has been studied by Farzad *et al.,* [3]. They concluded that the increasing of the nanoparticle volume fraction decreases the thermal entropy generation and increases the frictional entropy generation. The effects of addition of CNTs/Al2O3 nanoparticles in base fluid on thermal conductivity has been studied by Mohammad *et al.,* [4]. The numerical solution shows that the thermal conductivity of nanofluid depends directly on the solid volume fraction. Also, many numerical and experimental studies have been carried out on the effectiveness of nanofluids taken from previous studies [2-14]. They concluded that the addition of any type of nanoparticles (with thermal conductivity higher than that of base fluid) to base liquids enhances the thermal conductivity. Other works which are interesting in the use of nanofluids in heat exchangers can be found in Ref. [15-20]. The results demonstrated that the use of nanofluids has a positive impact on heat transfer in heat exchangers.

Applying a magnetic field to nanofluid forced convection has many effects on heat transfer. Magnetohydrodynamic (MHD) forced convection of nanofluid is one of the interesting topics for many researchers. This is due to important engineering applications such as nuclear reactors, heat exchangers, hydrodynamical machines, car radiators, and medical applications. In this context, the study of Karimipour *et al.,* [21] investigated numerically the laminar MHD forced convection flow of nanofluid (water/FMWNT carbon nanotubes) in a microchannel imposed to uniform heat flux. The results have shown that the fully developed velocity profile varied with Hartmann numbers. This means that increasing the magnetic field strength in order to increase the heat transfer rate is applicable only in a limited range, and it is not effective beyond that range. Forced convective heat transfer of nanofluids in porous half-rings has been studied in the presence of a uniform magnetic field by Sheikholeslami *et al.,* [22]. The results indicated that the Nusselt numbers decreased with the increase in Lorentz forces. The research work of Aminossadati *et al.,* [23] studied the magnetic field impact on forced convection of Al2O3 -water in a partially heated microchannel. The results reported that the microchannels are better in terms of heat transfer for higher Reynolds and Hartmann numbers. The effect of a magnetic field on free convection of three types of nanofluids: (copper/water, alumina/water and silver/water) has been studied by Hamad *et al.,* [24]. The numerical results show that the increase in the values of the magnetic parameters leads to a diminution of the velocity magnitude and to the parameter heat transfer rate for fixed values of nanoparticles concentrations. The influence of the external magnetic field on forced convection of ferrofluid (Fe3O4–water) is taken from the study by Sheikholeslami *et al.,* [25]. They found that the Nusselt number is a decreasing function of the Hartmann number. Selimefendigil *et al.,* [26] interspersed by the role of magnetic field in forced convection of CuO-water. The results demonstrate that the Hartmann number has positive effects on the average Nusselt number, and it was varied with the inclination angle of the lower branching channel. The magnetohydrodynamic mixed convection flow has been studied by Ishak *et al.,* [27]. Their results show that the magnetic field parameter plays an important role in controlling the boundary layer separation. The numerical study of Selimefendigil *et al.,* [28] discussed the role of magnetohydrodynamic on the forced convection of CuO-water nanofluid flow in a channel with four circular cylinder blocks. The results show that the average Nusselt number increases about 9.34% when the value of Hartmann's number is increased from Ha=5 to Ha=10. More discussions on the effect of the magnetic field can be found in Ref. [29-36].

Viscous dissipation plays a role as an internal heat generation source in affecting energy transfer, which affects temperature distributions and heat transfer rates. This heat source is caused by the shearing of fluid layers. In this context, Orhan and Avci [37] numerically studied laminar forced convection with viscous dissipation between two parallel plates. The results found that the variations of the temperature distributions directly depend on the Brinkman number. Increasing the Brinkman number increases the Nusselt number on the heated wall when the movement direction of the upper plate and the main flow are in the same direction, while the opposite is true for the movement of the upper plate in the opposite direction. The heat transfer and entropy generation of a magnetohydrodynamic flow of a viscous incompressible electrically conducting Casson hybrid nanofluid between two infinite parallel non-conducting plates in a rotating frame has been studied by Das *et al.,* [38]. The results show that the minimization in entropy generation is achieved for Casson hybrid nanofluid in comparison with Casson nanofluid. The impacts of viscous dissipation on MHD flow of a fluid in a vertical plate has been studied by Khaled *et al.,* [39]. The results show that the fluid velocity, fluid temperature, the shear stress, and the rate of heat transfer at the wall increase as the Eckert number, Grashof number, thermal conductivity, and the magnetic field increase. Two and three dimensional study of Joule and viscous heating effects of magnetohydrodynamics nanofluid Al2O3-water forced convection in microchannels were numerically studied by Mousavi *et al.,* [40]. They showed that considering Joule and viscous heating effects increases with the enhancement of the magnetic field intensity. Sheikholeslami and Abelman [41] studied the two phase flow of nanofluid in the presence of an axial magnetic field. The effect of viscous dissipation is taken into account. The results show that Nusselt's number is directly related to the aspect ratio and Hartmann's number, but inversely related to Reynolds's number, Schmidt's number, Brownian motion, and Eckert's number. The flow and heat transfer characteristics in three dimensions over a flat surface that is stretched, with the presence of viscous flow has been numerically studied by Mehmood *et al.,* [42]. They concluded that the impact of the Prandtl number on temperature varies depending on the presence of viscous dissipation. When viscous dissipation is present, an increase in the Prandtl number leads to higher temperatures. However, in the absence of viscous dissipation, increasing the Prandtl number results in a decrease in temperature across the channel. The effect of thermal radiation and chemical reaction on MHD free convective heat and mass transfer and the impact of the nanofluid has been investigated on an infinite moving upright plate, Arulmozhi *et al.,* [43]. They showed that the addition of nanoparticles in pure water reduces the velocity and when the chemical reaction parameter increases, the solutal boundary layer thickness decreases. The effects of a magnetic field, with suction and injection, and radiation terms on velocity and thermal slips have been studied by Guled *et al.,* [44]. Their results show that the skin friction increases with higher suction parameter values, magnetic parameters, and the skin friction value decreases as the slip parameter value increases.

According to the literature mentioned above, the entropy generation is one of the most important quantities which interests many researchers. The impacts of addition of nanoparticles and magnetic force in laminar forced convection on the entropy generation rate has been investigated by Atashafrooz *et al.,* [45]. They concluded that the magnitude of the total entropy generation for Al2O3–H2O nanofluid is less compared to CuO–H2O nanofluid. The total entropy generation along the hot channel is reduced significantly with increasing the Lorenz force, and it increases with addition of nanoparticles. These results are discussed in Ref. [46-48].

Many prior studies involving magnetohydrodynamic forced convection flow do not analyze the impact of viscous terms. The novelty of the present study is to investigate numerically laminar MHD forced convection flow of nanoliquid in a rectangular channel with an extended surface, moving top wall and three cylindrical blocks in the presence of a viscous dissipation term. Effects of influential non dimensional parameters (Reynolds number, Hartmann number, Eckert number and nanoparticles volume fraction) on temperature field distribution, stream function, entropy generation and mean Nusselt number are studied in detail.

2. Problem Configuration and Mathematical Formulation
2.1 Problem Considerations

The present study has been simulated in a two-dimensional rectangular channel with an extended surface crossed by Cu–water nanoliquid and containing three-cylinder hot blocks. The length (L=21H) and the height (2H) of the channel. The length of the extended surface is equal to 3H. A first hot cylinder block of diameter (D=H) is placed in the middle of the channel in the Y direction and the center of the first cylinder in the X direction is placed at 5H. The distance between the cylinders is equal to 5H. The nanoliquid and the top wall move with a constant velocity Uin and Uw respectively, and a cold temperature. A uniform temperature of three-cylinder blocks, extended surface, and bottom wall are imposed. A uniform magnetic flux with uniform intensity B0 acts along the Y-axis, its orientation forms an angle. The 2D schematic of this configuration is described in Figure 1. The thermophysical properties of water (base-liquid) and the copper nanoparticles are presented in Table 1 by Santara *et al.*, [50].

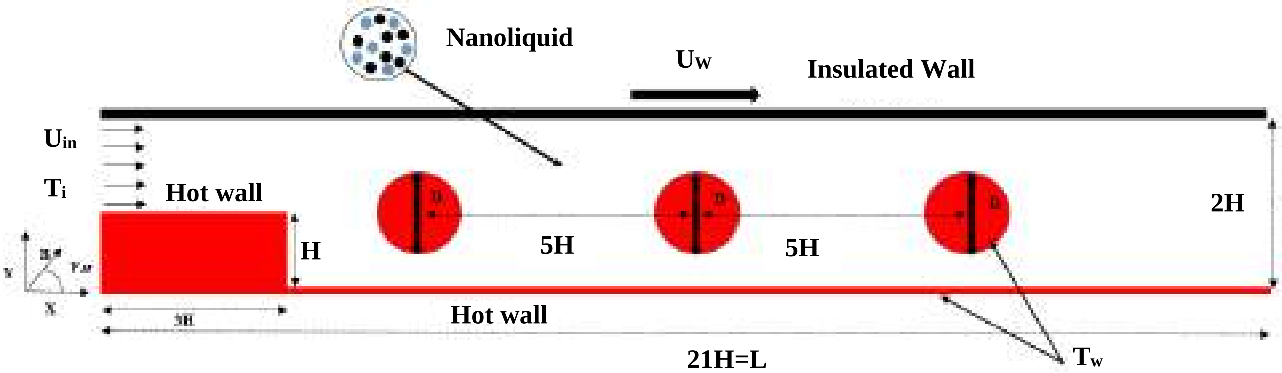


Fig. 1. Schematic of the physique problem

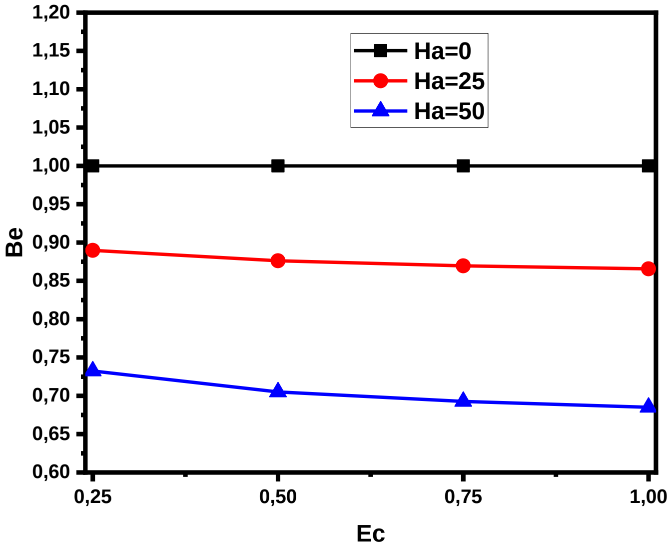
Table 1
Thermo-physical properties of base water and the Cu nanoparticle Santara *et al.,* [50]

Physical properties	Water	Cu
$C_P (J.kg^{-1}.K^{-1})$	4181.8	383.1
ρ (kgm^{-3})	1000.52	8954
$k (W.m^{-1}.K^{-1})$	0.597	386
β (K^{-1})	21×10^{-5}	51×10^{-6}
σ $(\Omega m)^{-1}$	0.05	2.7×10^{-8}
$\mu\times10^{4}$(kg/ms)	8.55	-

2.2 Governing Equations

In order to write the mathematical model, the following assumptions are used:

i. Steady state flow
ii. The flow is supposed to be incompressible, laminar, and two-dimensional.
iii. The magnetizing force due to the weak magnetic dipole moment is neglected as compared to the Lorentz force.
iv. The mixture of the base fluid and suspended nanoparticles is treated as a single phase with homogeneous effective properties.
v. The fluid is supposed to be Newtonian
vi. The thermo-physical properties are supposed to be constant.



(b)

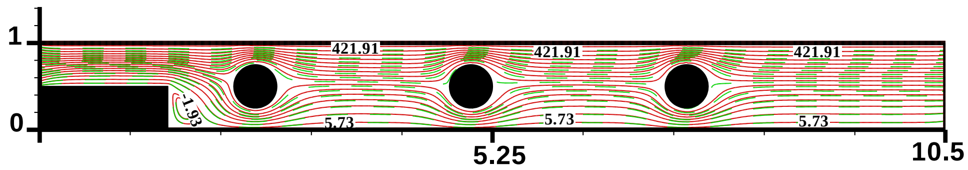
Fig. 23. Variation of the total entropy generation (a)and the Bejan number (b) for different Eckert number at Re=50; Ha=25; ϕ=0.02

4.7 Effects of Nanoparticles Volume Fraction

Figure 24 shows the effect of volume fractions of the nanoliquid on streamlines and isotherms for Re=50; Ha=0; Ec=0.5. From this figure, the streamlines of pure liquid are represented by a continuous line, and those for the nanoliquid are represented by a dashed line. It is noticeable that the streamlines of the nanoliquid are more compressed.

This figure demonstrates that the nanoliquid flow was approaching the cylindrical blocks, the streamlines were deflected toward the hot wall. The maximum value of the stream function is equal to (Ψmax=474.588) detected for pure water. The addition of nanoparticles in water decreases the value of stream function. This is due to the diminishing of the velocity flow of nanoliquid (cu-water).

For ϕ=0.02
Ψ_{min}=-3.500
Ψ_{max}=474.588



For ϕ=0.04
Ψ_{min}=-3.314
Ψ_{max}=450.259

Fig. 24. Streamlines and isotherms contours for ϕ=0.04at Re=50; Ha=0; Ec=0.5

Figure 25 and Figure 26 shows the effect of volume fractions of the nanoliquid on the average and local Nusselt numbers for Re=50-100-150; Ha=0; Ec=0.5. The average and local Nusselt numbers increase with the increasing of nanoparticles volume concentration in nanoliquid. The average Nusselt number increases linearly, and the maximum value detected for ($\boldsymbol{\phi = 0.04}$), the addition of nanoparticle in pure liquid enhances the heat transfer by about 7% for Re=50. The reason of this physical phenomenon can be attributed to two factors: the heightened thermal conductivity of the nanoliquid and the enlarged surface area of nanoparticles. This suggests that using nanoliquid is beneficial for improving heat transfer.

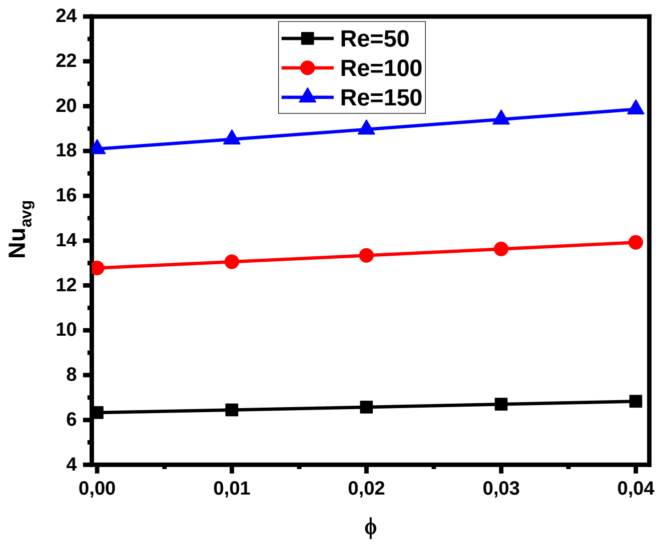


Fig. 25. Variation of Nu_{avg} in function of nanoparticle volume fraction for Re=50-100-150; Ha=0; Ec=0.5

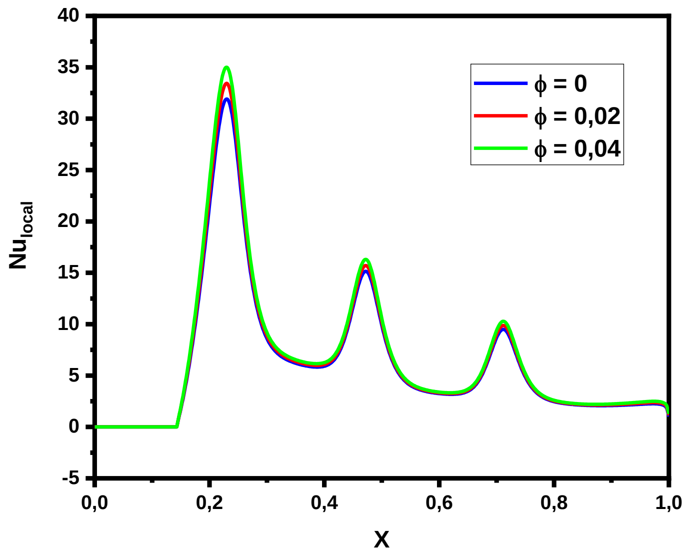
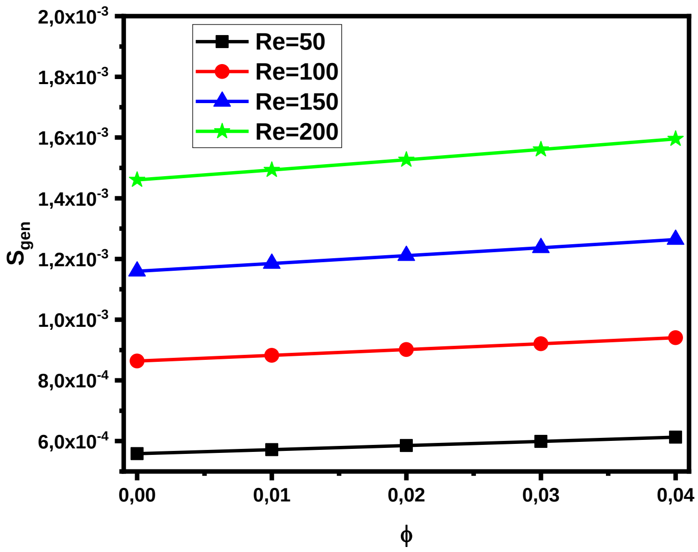
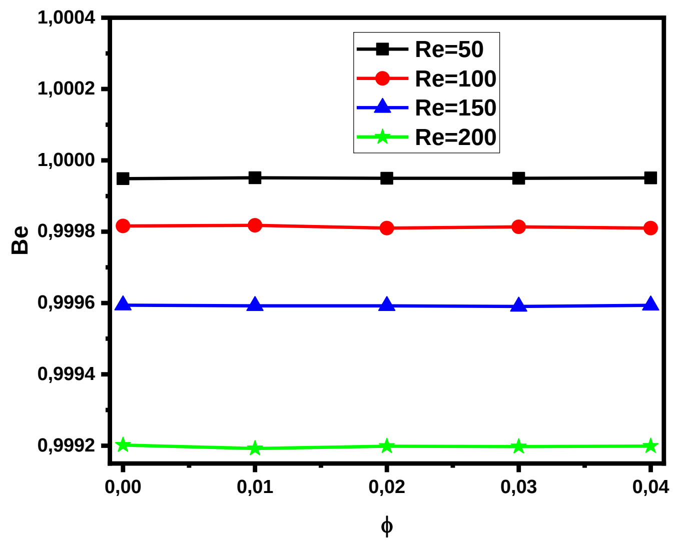


Fig. 26. Variation of Nu_{local} for different nanoparticle volume fraction at Re=50; Ha=0; Ec=0.5

The influence of nanoparticle volume fraction on the total entropy generation and the Bejan number for Re=50-100-150-200; Ha=0; Ec=0.5 is shown in Figure 27. Accordingly, as the nanoparticle volume fraction increases, the total entropy generation increases linearly and the Bejan number decreases. It is due to the additional sources of irreversibility introduced by nanoparticles. This means that there is a direct and proportional relationship between the total entropy generation and nanoparticle volume concentration. It can be explained by the improvement of the term relative to heat transfer irreversibility. It can be concluded that the addition of nanoparticles increases the thermal conductivity of the liquid, which enhances heat transfer between the nanoliquid and the surrounding surfaces, leading to higher thermal irreversibility and entropy generation. Also, this is due to the presence of solid type nanoparticles in the base liquid.



(a)



(b)

Fig. 27. Variation of the total entropy generation (a) and the Bejan number (b) for different nanoparticle volume fraction at Re=50-100-150-200; Ha=0; Ec=0

5. Conclusions

In this research, laminar MHD forced convection flow of a nanoliquid in a channel with an extended surface and three cylindrical blocks, in the presence of viscous dissipation. The imposed magnetic field was assumed to be uniform and constant. The LBM approach was used for simulation of nanoliquid laminar flow and heat transfer.

The interest was focused on the influence of the Reynolds number (Re), magnetic field (Ha), viscous dissipation (Ec) and nanoparticles volume fraction on streamlines and isotherms contours, local and average Nusselt number, velocity and the temperature profile, the total entropy generation (Sgen) and the Bejan number (Be). The main findings of this study can be summarized as follows:

i. The value of the stream function is enhanced significantly as the Reynolds number, Hartmann number, Eckert number are reduced with the addition of nanoparticles.
ii. Heat transfer of nanoliquid in terms of local and average Nusselt number is ameliorated when the value of Reynolds number, Eckert number, and nanoparticles volume fraction is enhanced. And it decreased when Hartmann's numbers increased. The heat transfer depends directly on the inertial force, Lorenz force, and viscous dissipation.
iii. The evolution of the heat transfer rate reaches up to 7% when 0.04 of the nanoparticles is added to the liquid. This confirms the effectiveness of using nanoparticles.
iv. The translation of the upper wall leads to an improvement in the heat transfer rate.
v. The velocity profile component increased with Reynolds number and Eckert number while it decreased with an increasing Hartmann number.
vi. The temperature profile component of nanoliquid decreases with Reynolds number, Hartmann number, Eckert number.
vii. The irreversibility represented by the total entropy generation increases according to the Reynolds number, Hartmann number, Eckert number and nanoparticles volume fraction.
viii. The irreversibility of nanoliquid depends on the inertial force, magnetic force, viscous dissipation term, conductivity and nanoparticles concentration.
ix. The bean number is reduced with high values of Reynolds number, Hartmann number, Eckert number and nanoparticles volume fraction.

As a future work, we can study the effect of multi-magnetic field on the heat transfer rate. Also, we can extrapolate this study to the case of nanoliquid flow in porous media.

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