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New thermodynamics of entropy generation minimization with nonlinear thermal radiation and nanomaterials

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ABSTRACT

This research addressed entropy generation for MHD stagnation point flow of viscous nanofluid over a stretching surface. Characteristics of heat transport are analyzed through nonlinear radiation and heat generation/absorption. Nanoliquid features for Brownian moment and thermophoresis have been considered. Fluid in the presence of constant applied inclined magnetic field is considered. Flow problem is mathematically modeled and governing expressions are changed into nonlinear ordinary ones by utilizing appropriate transformations. The effects of pertinent variables on velocity, nanoparticle concentration and temperature are discussed graphically. Furthermore Brownian motion and thermophoresis effects on entropy generation and Bejan number have been examined. Total entropy generation is inspected through various flow variables. Consideration is mainly given to the convergence process. Velocity, temperature and mass gradients at the surface of sheet are calculated numerically.

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1. Introduction

Fluids mechanics is an active field of research with many complex problems. These problems are solved using different techniques through computers. Fluids have a transporting ability. That is why it is used as mechanical, chemical, civil, petrochemical, metallurgical, ecological and biological engineering. Recently many experimental and theoretical investigations have been conducted by the scientists and engineers just to increase the rendition of production of industrial process. Engineers and scientists have experimentally observed that heat transport is necessary for superiority of multi scale production. Naturally, thermal features are accomplished via continuous phase liquids. However their significance is restricted by limited heat transport capabilities. Therefore researchers thought that enhanced heat transport phenomenon should be employed to attain the estimated outcomes. To obtain such objectives, they found that thermal capability of a continuous phase liquid can be enhanced through intensification of its thermal conductance. Thus the information of introducing materials into continuous phase liquid to deliver improved transport medium is introduced. The nanomaterials have much curiosity through their distinctive chemical and physical characteristics. It is regarded that insertion of nanomaterials increases thermal characteristics of continuous phase liquid. Therefore convective heat transport through nanomaterials has received the attention of excited researchers due to their increasing demands. Choi [1] initially gave the concept of nanomaterials. He defined such idea of nanomaterials in a continuous phase liquid. He experimentally proved that thermal characteristics of continuous phase liquid in increased through such type of nanomaterials. Buongiorno [2] presented research on nanomaterials by giving a model to analyze the thermal characteristics of continuous phase liquids. He anticipated that the enhancement in conductance of continuous phase liquid is due to the small size and low volume fraction of supplementary nanoelements. There is great importance of nanotechnology in many fields for example chemical and metallurgical devices, transportation, microscale objects, cancer therapy, power generation, etc. Heat transport in flow of copper-water nanomaterial towards stretched cylinder is investigated by Pandey and Kumar [3]. They implemented $(RKF45)$ technique to obtain the computational results for nonlinear ordinary differential equations. The effects of pertinent flow variables are presented through graphs. In this paper volume fraction of nanomaterial is considered 0–6%. Furthermore temperature field is increased with larger volume fraction parameter. The obtained outcomes are compared with available results and good agreement

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Nomenclature

$u,\ v$	velocity components
$x,\ y$	space coordinates
T	temperature
T_f	convective fluid temperature
T_∞	ambient temperature
C	fluid concentration
C_∞	ambient concentration
u_w	stretching velocity
u_e	external flow velocity
α^*	thermal diffusivity
B_0	strength of magnetic field
ν	kinematic viscosity
μ	dynamic viscosity
ρ	fluid density
ρ_p	particle density
c_p	specific heat
Q_0	heat generation/absorption coefficient
q_r	radiative heat flux
τ	capacity ratio
k	thermal conductivity
h_f	convective heat transfer coefficient
f	dimensionless velocity
η	dimensionless space variable
ϕ	dimensionless concentration
θ	dimensionless temperature
ψ	stream function
M	magnetic parameter
α	thickness parameter
γ	chemical reaction parameter
A	ratio of velocities
R	radiation parameter
Pr	Prandtl number
Θ_w	temperature ratio parameter
Nt	thermophoresis parameter
Nb	Brownian motion parameter
δ	heat generation/absorption parameter
Sc	Schmidt number
β_i	Biot number
Nu_x	local Nusselt number
Re_x	local Reynolds number
σ^*	Stefan–Boltzmann constant
k^*	coefficient of mean absorption
D_B	Brownian diffusion coefficient
D_T	thermophoresis diffusion coefficient
σ	electrical conductivity
φ	inclination of magnetic field
b^*	dimensional constant
Br	Brinkman number
L	diffusive parameter
N_G	dimensionless entropy
$\triangle T$	temperature difference
Re_x	Reynolds number
$a,\ c$	positive constants
q_w	surface heat flux
τ_w	surface shear stress
n	power index
R^*D	D the mass diffusivity and R^* the constant
α_1	dimensionless temperature difference
α_2	dimensionless concentration difference
Be	Bejan number
S_G	dimensional entropy
K	reaction rate

is noticed. MHD flow of nanomaterial with prescribed surface heat flux towards a bidirectional nonlinear stretched sheet is explored by Mahanthesh et al. [4]. They used suitable transformation to convert the governing flow expressions into ordinary ones and then tackled by a well-known shooting procedure. Surface drag force and Nusselt number are computed and discussed for different flow variables. Present outcomes are compared with published articles in literatures. Heat transport of nanomaterials by a rotating disk is studied by Yin et al. [5]. Outcomes depict that for an increase in stretching variable the surface drag force, heat transfer rate and velocity in radial and axial direction are enhanced increase but contrast behavior is observed for tangential component of velocity. Gupta et al. [6] examined MHD chemically reactive stagnation point flow over inclined stretched surface with radiative heat flux. Jeffrey–Hamel flow in non-parallel walls by homotopy transform technique is studied by Singh et al. [7]. Kumar et al. [8] investigated fractional model for convective radial fins in the presence of variable thermal conductivity. Few latest investigations regarding characteristics of nanomaterials may be found in refs. [9–36].

Thermodynamics second law with entropy generation minimization (EGM) is initially employed by Bejan [37]. He covered EGM particularly in the field of heat transport, storage and thermal power conversion. Optimizing thermal engineering devices is possible for larger energy effectiveness through thermodynamics methodology. To get such objectives, entropy generation minimization is utilized to control accessible irreversibility in a procedure. The above analysis clearly demonstrates that thermodynamics second law is much trustworthy than the thermodynamics first law to elaborate the heat transport capability in a system. Therefore additional consideration are given to improve the heat transport in engineering and electronic systems. Heat transfer enhancement through silver water and copper water nanomaterial with entropy generation in mixed convective flow by a rotating disk is studied by Hayat et al. [38]. They accounted two types of nanoparticles i.e., silver and copper. Entropy generation analysis is used via thermodynamics second law. Furthermore impact of nanoparticles on thermal conductivity of base liquid and entropy generation are discussed through graphs. Entropy generation in radiative flow due with rotating disk in presence of viscous dissipation and Joule heating is explored by Hayat et al. [39]. They used homotopy analysis technique to construct the series solutions of nonlinear expressions. Clearly entropy generation rate depends on velocity and temperature distributions. Furthermore entropy generation rate is decreasing function of magnetic variable, Reynolds number and Eckert number. Zhu and Yu [40] studied entropy generation and heat sink of thermoelectric cooler. They developed optimization model for thermoelectric cooler through entropy generation minimization. In this study total rate of entropy generation, exergetic efficiency and entropy number are proposed as optimization objective functions. Furthermore heat capacity of cooling liquid through heat sink is optimized. There obtained outcomes showing that minimum entropy generation number and total entropy generation rate can be accomplished in the presence of heat capacity rate of cooling liquids. Some new literature regarding entropy generation may be found in Refs. [41–45].

Entropy generation in flow of nanofluid towards a stretched surface is not discussed. Hence objective of current analysis is to discuss the effects of nonlinear thermal radiation and heat generation/absorption. Stagnation point flow is considered. Convective condition of heat transfer is discussed. Zero mass flux condition is

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