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Entropy generation minimization (EGM) of nanofluid flow by a thin moving needle with nonlinear thermal radiation

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ABSTRACT

Entropy generation minimization (EGM) and heat transport in nonlinear radiative flow of nanomaterials over a thin moving needle has been discussed. Nonlinear thermal radiation and viscous dissipation terms are merged in the energy expression. Water is treated as ordinary fluid while nanomaterials comprise titanium dioxide, copper and aluminum oxide. The nonlinear governing expressions of flow problems are transferred to ordinary ones and then tackled for numerical results by Built-in-shooting technique. In first section of this investigation, the entropy expression is derived as a function of temperature and velocity gradients. Geometrical and physical flow field variables are utilized to make it nondimensionalized. An entropy generation analysis is utilized through second law of thermodynamics. The results of temperature, velocity, concentration, surface drag force and heat transfer rate are explored. Our outcomes reveal that surface drag force and Nusselt number (heat transfer) enhanced linearly for higher nanoparticle volume fraction. Furthermore drag force decays for aluminum oxide and it enhances for copper nanoparticles. In addition, the lowest heat transfer rate is achieved for higher radiative parameter. Temperature field is enhanced with increase in temperature ratio parameter.

1. Introduction

Axisymmetric flow and heat transport over thin moving needle have been examined by the researchers in the presence of different flow conditions. It is attracted due to various industrial and technological applications like microscale cooling devices for heat elimination application, shielded thermocouple for determining the velocity of wind or hot wire anemometer, microstructure electronic devices etc. The structure of needle is just like paraboloid of revolution parallel to flow. Initially boundary layer flow by a thin needle is investigated by Lee [1]. In this study, control data 1604 digital computer is used to compute numerical solution of ordinary differential equations. Heat transport and nonlinear radiative flow by a moving thin needle with entropy generation in a parallel stream is examined by Afridi and Qasim [2]. The flow problem is self-similar with dissipation and nonlinear thermal radiation. They used fourth order Runge Kutta technique via shooting technique. Further nonlinear expressions for Bejan number and volumetric entropy generation have been obtained with the help of appropriate similarity transformations. The obtained results show that Bejan number and entropy generation rate decay verse radiative variable and smaller the size of needle respectively. Heat transfer and flow investigation over a constantly moving needle in a nanoliquid is presented by Soid et al. [3]. Bvp4c in Matlab is used to obtain numerical results with fixed Prandtl number i.e., (Pr = 6.2). The physical variable of curiosity like surface drag force and Nusselt number are discussed with the help of various flow parameters. Further dual solutions are established when the thin needle and free stream move in the reverse directions. Single and multi-walls carbon nanotube flow with variable heat flux over a moving thin needle is analyzed by Hayat et al. [4]. ND solve shooting technique is implemented to solve the flow problem numerically. The outcome shows that velocity and temperature fields strongly depend upon values of a and nanoparticles volume fraction. MHD radiative flow of nanomaterial with Joule heating over an incessant thin moving needle is studied by Sulochana et al. [5]. They implemented Runge Kutta Fehlberg integration technique. Graphical outcomes are obtained to predict physical interpretation of various embedded variables. Furthermore it is noted that enhancing needle size considerably diminishes the flow and energy layers of both nanomaterials (i.e., Ag-kerosene and Ag-water).

Entropy generation minimization (EGM) concept is very essential in the mechanism of heat transport. Entropy is generated as a result of

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much irreversibility in a physical system for example electrical resistance, friction, chemical reactions, dissipation, thermal radiation etc. MHD flow of viscoelastic fluid with entropy generation minimization embedded in porous medium is investigated by Baag et al. [6]. The flow equations are solved implementing Kummer's function. Entropy generation minimization is computed considering Joule heating and dissipation. The obtained results present that velocity field decays for higher estimation of magnetic and viscoelastic variables. Further present results are compared with previous literature and found good agreement. Govindaraju et al. [7] examined entropy generation in MHD nanomaterial flow towards a stretchable surface. They implemented Lie's scaling group of transformations to convert PDEs into nonlinear ODEs. Entropy generation minimization on non-Newtonian flow of nanoliquid by a permeable shrinking/stretching surface is explored by Qing et al. [8]. Nonlinear radiative heat flux and chemical reaction are also considered. The obtained nonlinear ordinary differential system is tackled by utilizing successive linearization method with Chebyshev. MHD nanomaterial stagnation point flow with entropy generation minimization over a stretchable surface is scrutinized by Bhatti and Rashidi [9]. Successive linearization technique and Chebyshev spectral collocation method are implemented to solve highly nonlinear differential equations. Hayat et al. [10] explored peristaltic flow with entropy generation in the presence of different shapes of nanofluid. Some recent investigations on entropy generation and stretched flow are mentioned in Refs. [11–15].

This paper discusses entropy generation minimization (EGM) of nanofluid flow over a thin moving needle in a parallel stream. Energy expression is modeled through nonlinear radiation and dissipation. Three different types of nanomaterials are utilized to enhance the thermal conductivity of base fluid. Water is treated as ordinary fluid while nanomaterials comprise titanium dioxide, copper and aluminium oxide. Nonlinear governing expressions of flow problem are transferred to ordinary ones and then tackled for numerical solutions utilizing Built-in-shooting technique [16–18]. An entropy generation analysis is utilized through second law of thermodynamics. Outcome of pertinent variables is examined graphically on entropy generation minimization (EGM), Bejan number, velocity, temperature, velocity and temperature gradients.

2. Formulation

Forced convective flow of nanomaterials over a continuously thin moving needle with a constant velocity u_w is discussed. A schematic flow diagram is shown is Fig. 1, where (x, r) denote the axial and radial directions and a the needle size (see Fig. 1). The continuously moving needle is considered thin when its thickness does not exceed that of the momentum and thermal boundary layer. Nonlinear thermal radiation and viscous dissipation terms are incorporated in the energy expression. Water is treated as ordinary fluid while nanoparticles comprise titanium dioxide, copper and aluminium oxide. The pressure gradient along the body is neglected. An entropy generation analysis is utilized through second law of thermodynamics. Moreover it is also assumed that T_w and T_∞ denote the constant and ambient temperature of the needle $(T_w > T_\infty)$. The governing flow expressions under the

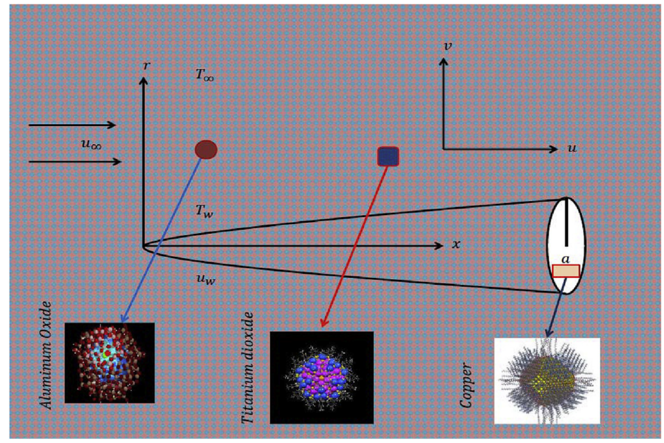

Fig. 1. Flow configuration and coordinate system.

above assumptions are [2,3]:

$$\frac{\partial}{\partial x}(ru) + \frac{\partial}{\partial r}(rv) = 0, \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial r} = \frac{\mu_{nf}}{\rho_{nf}}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right), \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial r} = \frac{k_{nf}}{(\rho c_p)_{nf}}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{1}{(\rho c_p)_{nf}}\left(\frac{16\sigma^* T^3}{3k^*}\frac{\partial^2 T}{\partial r^2} + \frac{16\sigma^* 3T^2}{3k^*}\left(\frac{\partial T}{\partial r}\right)^2\right) + \frac{\mu_{nf}}{(\rho c_p)_{nf}}\left(\frac{\partial u}{\partial r}\right)^2, \tag{3}$$

with

$$\left.\begin{aligned} &u \to u_w, \quad v = 0, \quad T = T_w \quad \text{at } r = R(x), \\ &u \to u_\infty, \quad T = T_\infty \quad \text{as } r \to \infty, \end{aligned}\right\} \tag{4}$$

where (u, v) represent respectively axial and radial components of velocity, (x, r) the cylindrical coordinates, $R(x)$ the surface shape of axisymmetric body, $(c_p)_{nf}$ the specific heat, σ^* the Stefan-Boltzman constant, k^* the mean absorption coefficient, ρ_{nf} the density, T the temperature, k_{nf} the thermal conductivity, μ_{nf} the dynamic viscosity and $(\rho c_p)_{nf}$ the heat capacity. Their definitions are

$$\left.\begin{aligned} &v_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}[(1-\phi)\rho_f + \phi\rho_s]}, \quad \rho_{nf} = (1-\phi)\rho_f + \phi\rho_s, \\ &\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}}, \quad (\rho C_p)_{nf} = (1-\phi)(\rho C_p)_f + \phi(\rho C_p)_s, \\ &\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\phi(k_f - k_s)}{(k_s + 2k_f) + \phi(k_f - k_s)}, \end{aligned}\right\} \tag{5}$$

Table 1
Thermal characteristics of continuous phase fluid and nanomaterials.

Base fluid and nanomaterials	Water	Aluminum oxide	Titanium dioxide	Copper
Molecular formula	H_2O	Al_2O_3	Tio_2	Cu
C_P(J/kgK)	4179	765	686.2	385
ρ(kg/m^3)	997.1	3970	4250	8933
k(W/mK)	0.613	40.0	8.954	400.0
$\alpha * 10^7$(m^2/s)	1.47	131.1	30.9	1163.1
$\beta * 10^{-5}$(1/K)	21	0.85	0.9	1.67