**Impact of Homogeneous- Heterogeneous Reactions in a Radiative Micropolar Nanofluid through Expanding Surface**

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**Abstract:** The flow of polar fluids has several importances in current real-life applications, including biomedicine, industries, etc. The study carried out here with an objective that the flow of polar conducting nanofluid associated to the interaction of thermal radiation over an elongating surface packed with a porous matrix. Moreover, the reacting species, embedding the homogenous and heterogeneous reactions, are inserted in the present investigation. The role of particle concentrations of both the “*single-walled carbon nanotube*” (SWCNT) and “*multi-walled carbon nanotube*” (MWCNT) in the flow phenomena has a greater impact with other characterizing factors. The mathematical model presented here is renovated into standard non-dimensional form, and then shooting embedding with “Runge-Kutta fourth-order” is exploited. The characteristics of the embedding factors are reported via graphs, and the physical behavior of these factors is elaborated in the discussion section with proper validation of the numerical results obtained in particular conditions.

**Keywords:** Micropolar nanofluid; CNT nanoparticles; Porous matric; Thermal radiation; Numerical technique.

**INTRODUCTION**

Modern cooling technology shows novel fluids to achieve efficient, cost-effective heat exchange. Among the base fluids those are used commonly as ethylene glycol (EG), oils, water, etc. In particular, EG is an imperative organic compound widely applied as a coolant in automotive engines and electronic devices for the low freezing and high boiling point. The mixture of EG and water with certain ratio are extensively used in diverse industrial processes, including automobiles, energy systems and heat transportation applications. Several researchers like Esfahani [1], and Sarkar [2] have presented various properties and the impact of ethylene glycol under diverse conditions. In another contribution, Arif et al.[3] explored the significant behavior of polar bi-hybridized nanofluid through an expanding permeable Riga plate. In particular, a hybrid nanofluid is obtained for the dispersion of silver and diamond nanoparticles into a base fluid containing water and EG as 80:20 ratio. By employing a suitable similarity rule, the governing equations are renovated into standard dimensionless form, and afterward, the modelled problems are tackled numerically using a built-in MATLAB routine. The analysis of rate coefficients under varying physical conditions with dual characteristics highlights a wide range of engineering and real-world applications. Ali et al.[4] investigated on a mixed convective flow along with suction in a polar fluid past over a slanted sheet by incorporating magnetic and radiative heat that enhances the behavior of flow dynamics. Further, Usfazi and Aly [5] examined several results on the polar fluid over a distorting plane by employing exact analytical techniques to the heat transfer phenomena under the action of several factors. The solution of these models within the proposed domain classifies the nature of the solutions, where the critical b-values demarcate regions of multiple solutions. Moreover, they observed that the velocity of the stretching surface decreases with increasing slip, while the Nusselt number attenuates with larger temperature jumps. The study proposed by Bhatti [6] reported the significance of bi-hybrid nanoliquid by dispersing *Au* and *MgO* nanoparticles in a grade non-Newtonian liquid. The study focused on flow within parallel plates under electromagnetohydrodynamic' behavior. The energy equation was modified to include viscous and magnetic dissipative heating effects. Since the governing differential equations were nonlinear, analytical solutions were derived using the perturbation technique. The findings revealed that the hybrid nanofluid significantly enhanced thermal conductivity, leading to heat transfer rate. Moreover, the flow was accelerated with higher free convection and stronger electric field effects. Further, In the study of Reddy et al.[7] explored in the role of velocity slip in the MHD flow with the combined behavior of thermo-diffusion and diffusion-thermo effects under suction/injection over an elongating surface. The modelled equations were solved numerically using the “Keller box method”. Their outcomes presented that the velocity profile enhances with higher values of the thermal and solutal Grashof number, while stronger magnetic field intensity and permeability exert a retarding effect on the flow. In another study, Bejwad et al. [8] reported two-dimensional nanofluid flow via an inclined wavy surface packed with a non-Darcy porous matrix. They have used the bvp4c solver to exhibits the results of several factors affecting the flow properties.

The studies reported in the literature section have various significance but some more physical interaction will enhance the structure of the present investigation and these are;

* To explore the significance of the carbon nanotubes (CNTs) nanoparticle in the polar polar nanoliquid considering in various profiles.
* The analysis of homogenous and heterogeneous chemical reactions with electrically conducting fluid for the interaction of magnetization has various impacts in real-world applications.
* The importance of permeability associated with thermal radiation from the assumption of Rosseland approximation shows its greater role on the flow phenomena.

**MATHEMATICAL ANALYSIS**

The carbon nanotube in the water based polar nanofluid over an stretching sheet crammed with absorbent matric is reported in the existing investigation. The interaction of SWCNT and MWCNT with water based nanofluid with the contact of magnetic field enhances the heat transfer properties. The main flow direction of the flow is towards the x-direction where the sheet is elongating and y-direction is normal to it. The stretching velocity is reported as  toward x-axis. Moreover, the variable magnetic field with strength B0 is imposed toward the transverse direction, which is imposed as(Fig.1). The assumption of thermal radiation and the homogeneous and heterogeneous chemical reaction also favors in enhancing the heat transport phenomena. The assumption abovementioned properties give rise to the following governing equation (Following Ahmad et al. [34]).

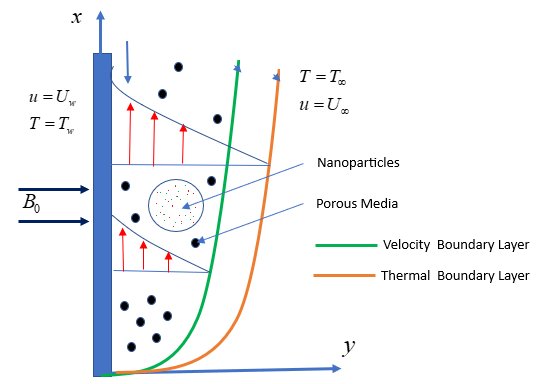


FIGURE .1 Geometrical configuration

, rate= (1)

, rate= (2)

 (3)

 (4)

 (5)

 (6)

 (7)

 (8)

The required surface conditions are

 (9)

The rotational viscosity in the present problem is assumed as  where the power n displays the characteristic of the surface. Particularly,  reported as the surface is flat and exhibits the motion is linear, , it becomes concave and , indicates the convex shape of the surface. The assumption of heat flux  from the Rosseland’s approximation, is expressed as

 (10)

However, a detailed containts used in the manuscript is presented in the manuscript.

The physical properties of the naofluid for the viscosity, density, conductivity, etc. are presented as

 (11)

**The Following Similarity Transformations are encrypted in the System as**

 (12)

With the help of above mentioned similarity variables the continuity equation satisfy automatically and the remaining equations are also transformed to

 (13)

 (14)

 (15)

 (16)

 (17)

However, the renewed boundary conditions are

 (18)

Further, the non-dimensional constraints are;

 (19)  
Particularly, and  are not identical, however it is expected that these are equivalent. Here, as per the assumptions the species and are considered as alike, i.e., , thus

 (20)

Therefore the equations (16) and (17) are converted into

 (21)

With proposed boundary conditions

 (22)

The engineering coefficients such as , the shear rate with the heat transfer rate are

 (23)

Here, heat flux () with shear stress () are

 (24)

The transformed modelled expressions are

 (25)

Here  is the local Reynolds number.

**TABLE-1:** **Physical assets of CNT nanoparticles with water**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  | 1600 |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

**TABLE-2: Reasonable examination of for **

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | | |
|  | **Ramachandran et al. [32]** | **Ishak et al. [33]** | **Present** |
| 0.71 | 1.7063 | 1.7063 | 1.70328729 |
| 1 | --- | 1.6755 | 1.67497732 |
| 7 | 1.5179 | 1.5179 | 1.51839171 |

**VALIDATION WITH PARAMETRIC BEHAVIOUR**

The variation of variable magnetism considering a polar nanofluid comprised of CNT nanoparticle i.e. SWCNT~water nanofluid and MWCNT~water nanofluid over an elongating surface within the permeable matrix is reported in this analysis. The behaviour of thermal radiation associated with the homogenous as well as heterogeneous reaction is resulted in the flow phenomena of the energy any and solutal profile is also exhibited. The thermophysical models, particularly the Mintsa model of thetrmal conductivity favors a significant role on the flow phenomena of nanofluids. **TABLE-1** represents the thermal properties of the CNT nanopartiocle with the water in a particular surrounding temperature is reported and collected from the earlier literature which is cited in the text. The mathematical model with the utility of similarity rules are renovated to its non-dimensional form and then tackled numerically utilizing shooting based Runge-Kutta technique. The simulation of the various factors on the flow phenomena are characterized by deploying certain factors and the remaining factors are treated as constants such as i.e. . The conformity of the present results are reported in **TABLE-2** where it represents the coincide results with Ramachandran et al. [32] and Ishak et al. [33] leading to the convergence property of the methodology.

**PARAMETRIC ANALYSIS**

The present mathematical model equipped with several factors on the flow phenomena of the axial as well as angular velocity along with the energy and solutal concentration. The profiles are associated to the M(Magnetic Parameter) which is arranged considering the range as and the results are reported on the axial as well as angular velocity. Moreover, the particle concentration is exhibited for the range of affecting the velocity and the temperature distribution. The impact of thermal radiation (Nr) is constructed on the temperature distribution considering the numerical range as and the homogenous reaction is reported as and heterogeneous reaction is considered as affecting the concentration profile.

In particular**, FIGURE.2 and FIGURE.3** depict the significant properties of the M for the interaction of applied magnetic field on the axial and the angular velocity, respectively. Here, the interaction of various factor without the role of magnetization is imported for the numerical value of *M*, as but the variation indicates the effect of magnetization on it.The results are presented for both the MWCNT and SWCNT -water nanofluids, respectively. The involvement of the magnetization of the imported magnetic field that generates the Lorentz force which is characterized as a resistive force and this causes a noteworthy retardation in the velocity distribution. As a result the velocity bounding surface of the axial velocity also retards. The significant analysis between the nanoparticle lead to reveals that MWCNT nanoparticles produces greater role than that of the SWCNT nanoparticles in the significant attenuation. As projected in the axial velocity, a reverse effect is rendered in the angular velocity and this behaviour is reported because of the rotational motion of the particle. Moreover, MWCNT-water nanofluid overrides the fact of SWCNT-water nanofluid due to enhanced density of the particle. **FIGURE.4 and FIGURE.5** signifies the behaviour of the concentration of the nanoparticles i.e.  used for SWCNT nanoparticle and similarly  employed for MWCNT on the axial and angular velocity distributions . In particular the numerical values considered as  indicate the behaviour of flow profile considering the pure fluid and the and the results of volume concentration is deployed for the increasing nonzero variations of the factors . The volume fraction is presented as the percentage of the concentration equipped with the base fluid water. The enhanced concentration of the particle encounters a significant increase in the axial velocity and this increase is because of the enhanced thermal conductivity which dominates the fact of density of the nanofluids. Further, the angular velocity opposes the fact with the increasing behaviour as presented in the corresponding figure. The influential properties of SWCNT shows greater influence in comparison to MWCNT within and further, it shows opposite behaviour. The significant contribution of the particle concentration of the nanoparticles on the fluid temperature is reported in **FIGURE.6.** The inclusion of the concentration has significant properties in enhancing the thermal properties of the model since the thermophical model contributed a factor concentration in each case. The inclusion of concentration further augments the thermal conductivity of the nanofluid which encourages in augmenting the fluid temperature. The higher conductivity of the nanoparticle MWCNT comparing to SWCNT give rise to enhanced temperature within the system. The contribution of radiative heat flux ensures the role of thermal radiation that affects the fluid temperature which is reported in **FIGURE.7.**The factor that measure the emitted electromagnetic substances from surface of the element. These substances are generally transformed into thermal energy which is generated as radiative heat. It is encountered that the enhanced radiation the energy accumulated at the surface region overshoots the profile and the fluid temperature increases. However, the involvement of the greater conductivity of the SWCNT nanoparticle shows gives a suggestive measure for the significant enhancement ion the lower conductivity.To enhance the temperature in comparison to the MWCNT nanoparticle with lower conductivity. Further, a peculiar situation is exhibited for the absence of radiation is that the temperature profile shows its backflow near the surface region**. FIGURE.8** signifies the role of volume fraction affecting the concentration profile. It is observed that the concentration of the particle and the solute particle is exhibited from the proposed figure. The characteristic rendered that increasing concentration the solutal thickness of the profile retards showing flatter in the thickness enhances. It is insignificant to observe the comparative analysis of the nanoparticles used however, a close observation reveals that SWCNT have greater impact in comparison to MWCNT~water nanofluid **FIGURE.9** portrays the effect of homogenous and heterogeneous reactions affecting the fluid concentration. It is indicted from the figure that the factors have retarding effects on the solutal concentration but the comparative analysis reported that the profiles of the solutal concentration became thicker in the case of homogenous whereas the thickness enhances.



FIGURE.2 on FIGURE.3 on



FIGURE.4on  FIGURE.5 on 



FIGURE.6  on  FIGURE.7  on 



FIGURE.8  on  FIGURE.9  on 

The computational results of the heat transfer rate are reported in **Table-3** for the variation of distinct factors. It is observed that with the increase of particle concentration attenuates the rate of heat transfer but the resistivity due to the magnetic parameter encourages the properties. Moreover, the radiative heat transfer property for the increasing behaviour of the thermal radiation significantly attenuates the profile.

**TABLE-3: Results Of  For Different Variation of Factors**

|  |  |  |  |
| --- | --- | --- | --- |
| Real Values | | | Response |
|  |  |  |  |
| 0.05 | 0.5 | 1 | 0.7254936 |
| 0.2 | 0.5 | 1 | 0.7251652 |
| 0.05 | 2 | 1 | 1.0122291 |
| 0.2 | 2 | 1 | 0.9834792 |
| 0.05 | 0.5 | 3 | 0.7135193 |
| 0.2 | 0.5 | 3 | 0.7165498 |

**CONCLUSION**

The conducting polar nanofluid through an extending surface packed with permeable medium is reported in this investigation. The impact of thermal radiation vis-a-vis homogenous and heterogeneous reaction affecting the on the conducting flow of polar fluid. This corresponding to augments the study. In a specific case, the rate heat transfer for the behaviour is reported. The physical behaviour of numerous components is confirmed and the significant remarks are laid down as;

* The investigation reported for the behaviour of factor in particular case validates the earlier work and this lead to the convergence of the methodology.
* The CNT nanoparticles regardless to the variation of magnetization retards the fluid velocity
* Without loss of generality, the fluid temperature supplements for the increasing particle concentration.
* Radiating heat effect due to the insertion of thermal radiation boost up the fluid temperature irrespective to the type of nanofluids but the greater conductivity of SWCNT nanoparticle shows greater influence in comparison to the MWCNT nanoparticles.
* Improved volume fraction counterproductive in retarding the solutal concentration within the domain and similar trend is encountered for the enriched homogenous and heterogeneous chemical reaction components.

**REFERENCES**

1. J. A. Esfahani, S. M. Reza, G. Masoud*,* et al.*,* Powder Technol. 317, 458 (2017).
2. S. Sarkar, N. R. Jana, S. Das, Int. J. Fluid Mech. Res. 47, 419 (2020).
3. A. Muhammad, S. Suneetha, T. Basha, et al.*,* Case Stud. Therm. Eng. 39, 102407 (2022).
4. B. Ali, I. Shafiq, Q. Jarad, et al.*,* Case Stud. Therm. Eng. 28, 101537 (2021).
5. W. K. Usafzai, E. H. Aly, Therm. Sci. Eng. Prog. 37, 101584 (2023).
6. M. M. Bhatti, O. A. Beg, R. Ellahi, et al., J. Magn. Magn. Mater. 564, 170136 (2022).
7. Y. D. Reddy, B. S. Goud, B. Alshahrani*,* et al.*,* Alex. Eng. J. 61, 8891 (2022).
8. N. N. Reddy, D. Y. Reddy, S. V. Rao, Int. Commun. Heat Mass Transf. 134, 106024 (2022).

**Appendix:**

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