Journal of Innovative Technology, Vol. 7, No. 1, pp. 51-58, March 2025
http://doi.org/10.29424/JIT.202503_7(1).0005

Symmetry scaling framework for heat and mass transfer in electromagnetic radiative MHD Powell-Eyring fluids numerically

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ABSTRACT

The convoluted dynamics of heat and mass transfer in magnetohydrodynamic Powell-Eyring MHD-PE fluids exposed to electromagnetic radiation cause notable logical challenges having non-Newtonian properties of these fluids. Magnetohydrodynamic Powell-Eyring fluids are very essential in computational fluid dynamics CFD having diverse rheologic features essential for specific simulations. This study examines the behavior of magnetohydrodynamic Powell-Eyring MHD-PE fluid model with effect of transferring heat and mass that produce approximate solutions of proposed model initially articulate by partial differential equations (PDEs), that are transformed into equivalent nonlinear ordinary differential equations (ODEs) by using similarity transformations. The solution dynamics for MHD-PE is generated numerically by using Adams' numerical solver and explicit Runge kutta technique for MHD-PE fluidic model . The performance is Evaluated and compared with different methods under similar conditions. These outcomes are analyzed along with the comparative study by varying Lewis number, Prandtl number, Eckert number, magnetic field parameter, radiation parameter, permeability parameter and fluid parameters. The efficiency and robustness, are portrayed through absolute error plots and solution plots for MHD-PE fluid model. Magnetohydrodynamic Powell-Eyring MHD-PE fluids enables researchers to grab complex fluid flow problems over various fields such as biomedical fluid dynamics, environmental fluid dynamics, industrial process and material science allowing particular estimate to fluid flow patterns.

Keywords: Magnetohydrodynamic Powell-Eyring MHD-PE fluid model, Heat transfer, mass transfer, electromagnetic radiation, Adams numerical solver, explicit Runge kutta technique.

NOMENCLATURE

*CF*D	Computational fluid dynamic
MHD-PE	Magnetohydrodynamic Powell-Eyring fluid model
PE	Powell-Eyring
PDE /ODE	Partial differential equation/Ordinary differential equation
σ	Conductivity of electricity
A_1	Fluid parameter
A_2	Fluid parameter
C_p	Heat specific at constant pressure
R	Radiation parameter
K	Permeability parameter
M	Magnetic field parameter
Pr	Prandtl number parameter
Ec	Eckert number
Le	Lewis number
DB	Mass diffusion
k	Porous parameter
c	Fluid concentration
T	Fluid temperature

Manuscript received September 17, 2024; revised November 7, 2024; accepted November 21, 2024.

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1. INTRODUCTION

Non-Newtonian fluidic models are used to precisely characterize the flow behavior of shear-thinning fluids, that are essential for the plastics and paint industries. These models effect several processes, such as creating polymer and paint applications [1]. Non-Newtonian fluids are common in many fields of engineering fluid mechanics, and they are suitable in thrilling properties which varies from Newtonian fluids [2]. One of the common non-Newtonian fluids is Eyring-Powell EP fluid originates from the kinetic theory of fluids [3]. Moreover, heat transfer [4] characteristics of Eyring-Powell EP shows a substantial role in thermal isolation [5], and geophysical process [6]. The Powell–Eyring fluid is an attractive non-Newtonian fluid that, despite being relatively complex [7], has numerous advantages among researchers [8]. Bilal and Ashbar investigate the stretching performance of Eyring Powell EP fluid under mixed convection flow situations [9]. Khan et al. observed movement of magnetohydrodynamic [10] transfer of heat behavior [11] for liquid polymers coated wire [12] in an absorbent medium by using Eyring Powell EP fluid model [13]. Oke observed the Powell Eyring stretching fluid's shear thickening features for heat transference [14-20]. Fluids with less viscosity are commonly used in polymer and industries because of exclusive flow features [21]. The MHD magnetohydrodynamic properties for the Powell Eyring fluid having radiating flux energy is explored by Faizan et al. [22]. Numerous fluidic models come in to existence for representing the performance of the material in chemical engineering structures, the Powell Eyring PE fluidic model is very beneficial due to its integrity and endurance so it is superior than other non-Newtonian systems. Due to remarkable physical phenomenon, the Powell Eyring PE fluid has efficiently studied by many scientists [23]. Seyedi et al. explored flow of Eyring Powell EP MHD and stated effects on chemical reaction, radiations, also the absorption of heat [24-29]. The mass and transfer of heat in Eyring Powell MHD nanofluidic flow in porous cone, for extracting and injecting is examined by Babu et al. [30-36]. The properties of Eyring Powell EP can be well improved by combining with microscopic small nanoparticles [37].

A key area of attention in recent research is to examine the transfer of heat and flow phenomena. Numerous sides of this focus are thoroughly investigated by Sakiadis's creative work on boundary sheet flow over a nonstop moving solid plane [38]. The increasing uses of heat and mass transmission through porous medium in modern industries, including chemical reactors, fire dynamics, room heating, and various other transfer of heat processes, become the attention of researchers and engineers. [39-41]. After most, in the existence of heat transfer study, Nadeem and Akbar have observed the MHD peristaltic movement of a dense Newtonian fluid in an unvarying network with varying viscosity [42]. Bejawada et al. observed the consequences of radiations on MHD investigation of a Casson fluidic movement on an arbitrary high surface using the chemical reaction inside a Forchheimer spongy media [43]. Thermal radiation enhances heat transfer in MHD fluids having a vital role in thermal power stations, gas, petroleum industries, and devices that transfer energy [44]. Pal and Mondal irregular cooling or heating on a stretched sheet in a porous substance, along with the effects of MHD on fluid movement and transfer of heat methods [45]. Recently, Hayat et al. studied effect of magnetohydrodynamic (MHD) limit line sheet contact of Powell Eyring PE nanofluids using thermal diffusion circumstances with Brownian motion over an outwardly dense stretching surface by examining heat transferring method certain with the adjustable thickness [46-47]. The empirical models used for non-Newtonian fluids (Powell Eyring) can now be extended to a full simulation of transfer of heat kinetics in liquids. Basic statement that industrial fluids and other non-Newtonian fluids can be defined due to transfer of heat by convection methods. The study of Powell Eyring fluids is developing outstandingly over time [48-50].

The following are the brief interpretation of study's discoveries and contribution:

- This study investigates the behavior of magnetohydrodynamic Powell-Eyring MHD-PE fluid model by manipulating Adams numerical method and explicit Runge Kutta method by using ND-solve to create synthetic dataset. The dataset is transformed to Matlab for comparison between the two methods in order to get the desired outcomes in the form of solution plots and absolute error plots.
- The intention of this study is to generate approximate solutions of present magnetohydrodynamic Powell-Eyring MHD-PE fluid model, initially stated by partial differential equations (PDEs), that are changed into equivalent nonlinear ordinary differential equations (ODEs) by using similarity transformations.
- The dataset for the outcomes is created mathematically using Adam's solver for magnetohydrodynamic Powell-Eyring MHD-PE fluid model by changing multi class parameters i.e., stagnation, magnetic, material, Eckert number, and heat generation parameters.
- The controlled methods reliably produce least error outcomes that thoroughly match to numerical findings over different magnetohydrodynamic Powell-Eyring MHD-PE fluid model variations.
- The effectiveness and robustness of these methods are depicted through solution plots analysis and absolute error analysis for magnetohydrodynamic Powell-Eyring MHD-PE fluid model variation.

The remaining work of the paper is arranged in the following way: part 2 explains the mathematical modelling of the micropolar magnetohydrodynamic (MHD-PE) fluid model. Part 3 describes solution methodology whereas Part 4 shows results and discussion with tabular and graphical illustrations. Part 5 contains conclusion of the micropolar magnetohydrodynamic (MHD-PE) fluid model with many potentials of future paths having noteworthy contributions to knowledge.

2. MATHEMATICAL MODELLING OF MHD-PE

This work discovers the performance of a fluid flow system moving on a flat surface generated by electromagnetic radiation effect within the MHD-PE system. The governing PDEs equations (1-4) for MHD-PE fluidic flow are given below:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\left(v+\frac{1}{\rho bc}\right)\frac{\partial^2 u}{\partial y^2}-\frac{1}{2bc^3\rho}\left(\left(\frac{\partial u}{\partial y}\right)^2\frac{\partial^2 u}{\partial y^2}\right)-\frac{\sigma B_\circ{}^2}{\rho}-\frac{v}{k}u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{1}{\rho c_p}\frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2}+\frac{u}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2 \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2} \tag{4}$$

Here is the similarity transformation for the above equation 1-4.

$$n=yx^{-\frac{2}{3}},\psi=x^{\frac{4}{3}}F(\eta),\theta=\theta(\eta),\varphi=\varphi(\eta) \tag{5}$$

The transmuted ODEs are given in equations 6-10 along initial boundary conditions.

$$(1+\lambda_1)F'''+FF''-2(F')^2-\lambda_1\lambda_2(F'')^2F'''-MF'-2k'=0 \tag{6}$$

$$\left(1+\frac{4}{3}R\right)\theta''+\mathrm{PrF}\,\theta'+Ec\theta'^2=0 \tag{7}$$

$$\varphi''+\frac{4}{3}LeF\varphi'=0 \tag{8}$$

$$F = S, F' = 1, \theta = 1, \varphi = 1, at\eta = 0 \tag{9}$$

$$F' \to 0, \theta \to 0, \varphi \to 0, at\eta = \infty \tag{10}$$

The transfer of heat and transfer of mass properties of fluids are particularly controlled with electromagnetic radiation effects. The diffusion of mass process effects the general performance of fluid. Energy at surface and wall species are presented by T_w and C_w correspondingly, that are supposed to turn significantly by the values of energy parameters and species parameters at T_∞ to C_∞ situated by some distance from plane shown in figure below. Fig.1 depicts geometrical flow diagram.

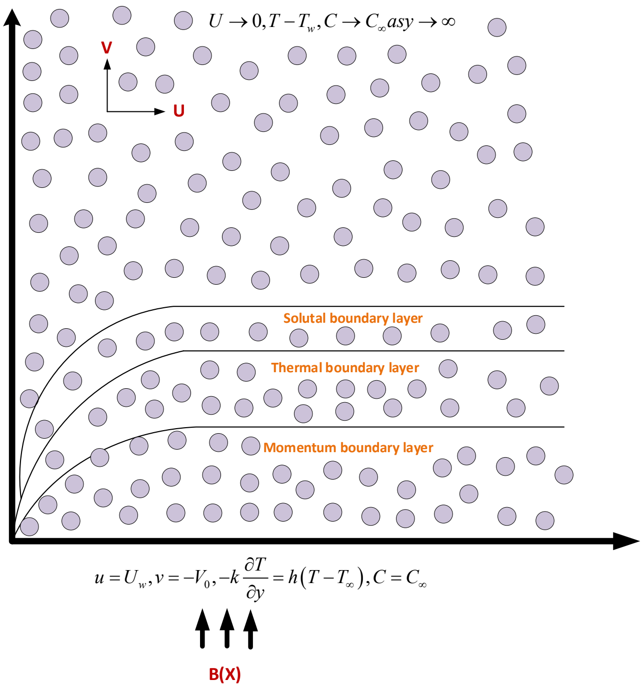

Fig. 1 Flow geometry of MHD-PE

3. SOLUTION METHODOLOGY

This segment describes the solution technique of nonlinear differential equations (1–4) for magnetohydrodynamic Powell-Eyring MHD-PE fluid model. To solve MHD-PE model Adams numerical method and explicit Runge kutta method is used to generate synthetic dataset using Mathematica "ND Solve" routine in Mathematica software using Adams' numerical solver and explicit Runge kutta technique for MHD-PE fluid model with the help of ND solver The dataset is formed for five situations, having three cases of each. The step size of the dataset is 0.025. The graphical abstract is depicted in figure 2 and Table 1 shows the variations of different parameters for magnetohydrodynamic Powell-Eyring MHD-PE fluid model.

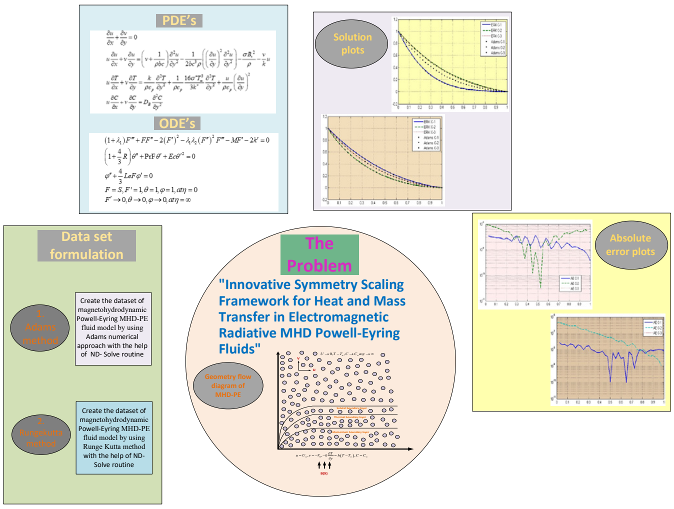

Fig. 2 Graphical abstract of Powell-Eyring MHD-PE fluid model

Table 1 Scenarios and cases for MHD-PE fluid model

Scr (1):	Scr (2):	Scr (3):	Scr (4):	Scr (5):
Case1=1.95	Case1=0	Case1=0	Case1=0	Case1=1
Case2=3.95	Case2=14	Case2=1	Case2=0.5	Case2=2
Case3=6	Case3=5	Case3=2	Case3=1	Case3=3.5

The dataset is transferred to matlab where the difference between adams' numerical method and explicit Runge kutta method is checked to get desired outcomes for Powell-Eyring MHD-PE fluid model. The efficiency is depicted through absolute error plots and solution plots for MHD-PE fluid model.

4. RESULTS AND DISCUSSION

In the given section, the mathematical modeling for Powell-Eyring magnetohydrodynamic MHD-PE fluid model is expressed by using comparison of outcomes produced by Adams' numerical method and explicit Runge-kutta method of the proposed MHD-PE fluid model by means of absolute error plots and solution graphs, creating a complex connection between electromagnetic forces, effect of heat and mass on these fluids. The synthetic dataset is generated numerically for Powell-Eyring magnetohydrodynamic MHD-PE fluid model in Mathematica software with the help of ND solver by using the explicit Runge-Kutta technique with Adams' numerical approach for the five scenarios each having three cases by putting $\eta(0, 1)$ with step size of 0.025. The dataset is then transferred to matlab the difference between Adams' numerical method and explicit Runge- kutta method for outcomes that are analyzed by varying Lewis, Prandtl number and Eckert numbers also magnetic field parameter, radiation parameter, permeability parameter and fluid parameters. The efficiency is depicted through absolute error plots and solution graph plots for MHD-PE fluid model. Figure (3-7) and subfigures 3(i, ii, iii)-7 (i,ii,iii) depicts the solution plots of MHD-PE fluid model for temperature, velocity, and concentration profiles. The MHD-PE fluid model displays minimum value of Absolute error, which approves its consistency with stated numerical outcomes in measuring the

MP-MHD-NF system's results. The accuracy of MHD-PE fluid model is further assessed through absolute error analysis. The highest and lowest range of absolute error of MHD-PE fluid system is depicted in figure 8-9 and subfigures 8(i, ii, iii) -9(i, ii,) for temperature, velocity, and concentration profiles. The lowest range of error matches to 10-11, whereas the highest range of error matches to 10^{-6} respectively. The significances of varying parameters λ1, M, R, K, Le for, velocity profile, temperature profile and concentration profiles are shown in Figure 3-9, subfigures 3 (i, ii, iii) - 9 (i, ii, iii) respectively. The Powell-Eyring magnetohydrodynamic MHD-PE fluid parameter λ1 has notable importance in the velocity profiles F′(η) for fluids like newtonian fluidic flow and the non-Newtonian fluidic flow. Fluid parameter λ1 is related by the Powell Eyring magnetohydrodynamic MHD-PE fluidic model, that depicts shear-thinning behavior of newtonian fluidic model with constant thickness. Rising the Powell-Eyring magnetohydrodynamic MHD-PE fluid model, the fluid parameter λ1 cannot directly affect velocity profile F′(η) for the newtonian fluidic system due to which they show constant thickness. Beside this non-newtonian fluids, Powell-Eyring magnetohydrodynamic MHD-PE fluid model show shear-thinning characteristics as their viscosity is not constant, with the rise of shear rate there is decrease in viscosity. In non-Newtonian fluids an Increase in the fluid parameter λ1 have an effect on the velocity profiles F′(η) .The consequences of M on temperature profile θ(η) and concentration profile ϕ(η) demonstrate that an increase in the M the temperature profile θ(η) of the fluid show a more improvement contrast to the heat intensity profiles θ(η) for the newtonian fluid. The magnetic field parameter M influences the depth of borderline layers but also deeply effect the heat intensity profile θ(η) and attentiveness profile ϕ(η) . Radiation parameter R on heat intensity profiles θ(η) is noticeable a raise in the radiation parameter R leads to enhance the energy profiles. In Newtonian fluid the increased in radiation parameter R effect is more noticeable in the heat intensity θ(η) of the Powell Eyring PE magnetohydrodynamic MHD-PE fluid model. Radiation parameter R has a considerable influence the energy dispersion in the MHD-PE fluidic flow model as it commands the heat intensity θ(η) .The influence of Le on, heat intensity θ(η) is noticeable as value of Le increase's momentum and thermal boundary layers both decreases due to which heat intensity θ(η) also decreases. The drop in the momentum and heat boundary layers enhances the thermal characteristics of MHD-PE fluids system. The parameter K shows varying effects on θ(η) both on newtonian fluids and the non-newtonian fluids. By increasing the parameter K in a porous medium, effect the θ(η) of newtonian fluids. This can improve fluid movement and improves heat transfer abilities, commonly uses in effective cooling and heating processes. when porosity parameter K exceeds heat transfer due to which there is a change in the movement of non-newtonian fluids. There is a connection among the performance of non-newtonian properties of fluid and rise in porosity parameter K give nonlinear temperature profiles θ(η) .

The accuracy of MHD-PE fluid model is further assessed through absolute error analysis. The MHD-PE fluid model displays minimum value of absolute error, which approves its consistency with stated numerical outcomes in measuring the MHD-PE fluid model results. The accuracy of MHD-PE fluid model is further assessed through absolute error analysis. The highest and lowest range of absolute error of MHD-PE fluid system is depicted in figure 8-9 and subfigures 8(i, ii, iii) -9(i, ii,) for temperature, velocity, and concentration profiles The lowest range of error matches to 10-11, whereas the highest range of error matches to 10^{-6} respectively. The numerical data of absolute error plots for scenarios 2, 3 and 5 give zero absolute error, as the difference between actual and predicted value is zero.

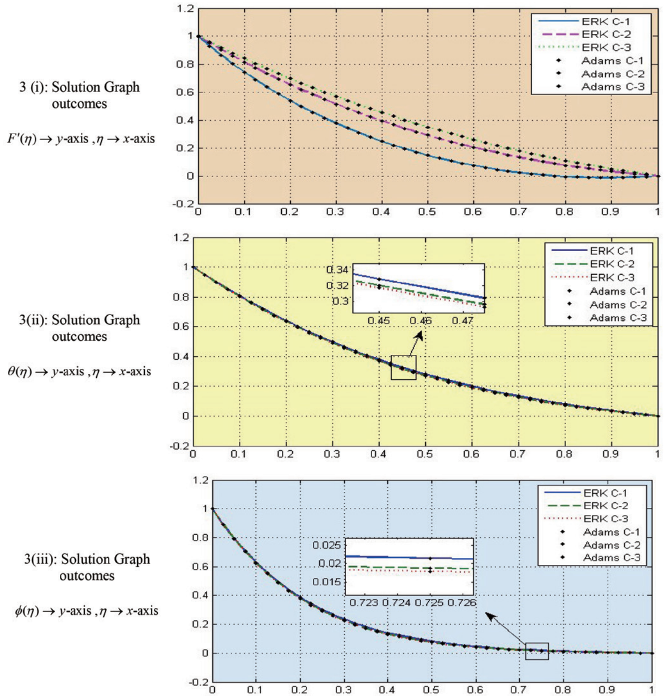

Fig. 3 Comparing the results of Adams and explicit Runge kutta with analyses on Solution graphs for MHD-PE fluid model for Scenario 1 of three cases by varying parameter λ1= 1.95, 3.95, 6.

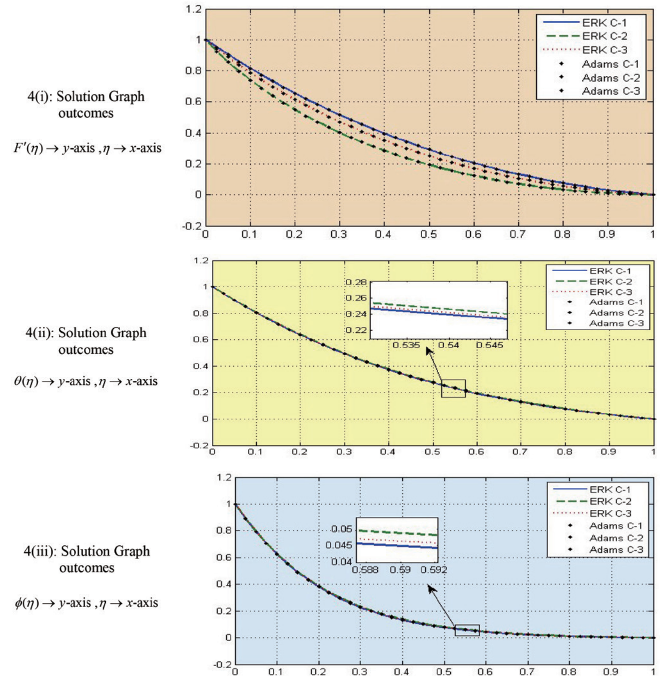

Fig. 4 Comparing the results of Adams and explicit Runge kutta with analyses on Solution graphs for MHD-PE fluid model, for Scenario 1 of three cases by varying parameters M= 0, 14, 5.

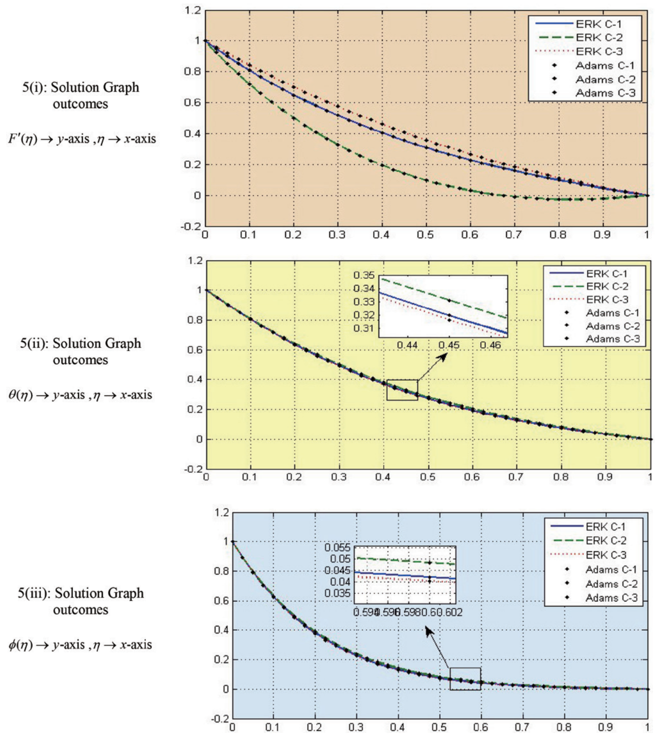

Fig. 5 **Comparing the results of Adams and explicit Runge kutta with analyses on Solution graphs for MHD-PE fluid model, for Scenario 3 of three cases by varying parameter K= 0, 1, 2.**

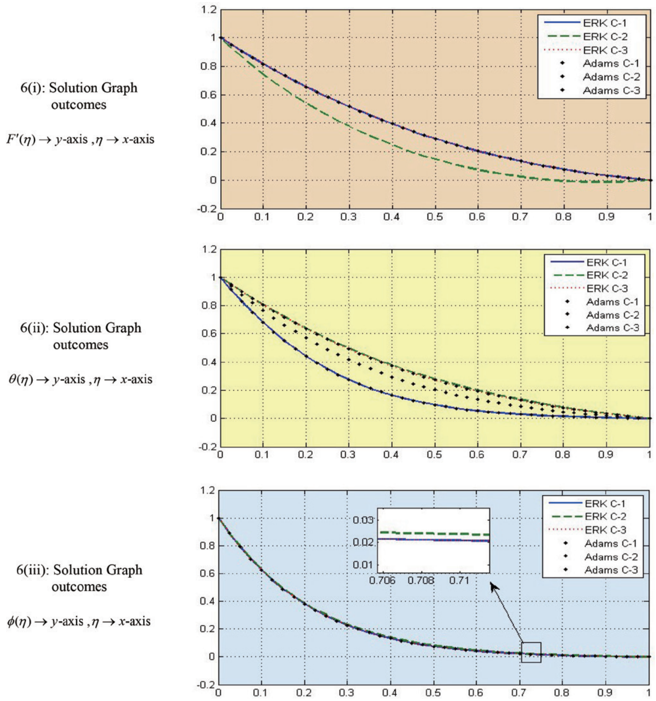

Fig. 6 **Comparing the results of Adams and explicit Runge kutta with analyses on Solution graphs for MHD-PE fluid model, for Scenario 4 of three cases by varying parameter R= 0, 0.5, 1.**

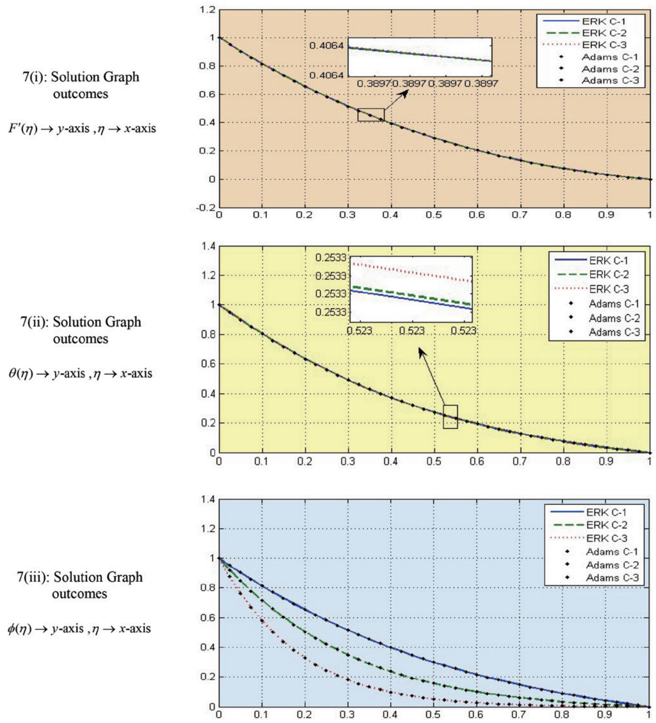

Fig. 7 **Comparing the results of Adams and explicit Runge kutta with analyses on Solution graphs for MHD-PE fluid model, for Scenario 5 of three cases by varying parameter Le= 1, 2, 3.5.**

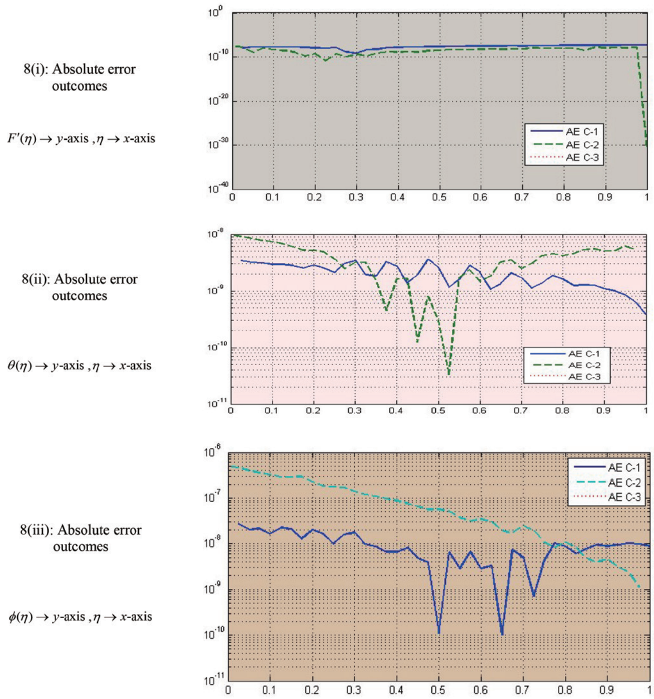

Fig. 8 **Comparing results of Adams and Runge kutta with analyses on absolute error for MHD-PE fluid model, for Scenario 1 of three cases by varying parameter λ1= 1.95, 3.95, 6.**

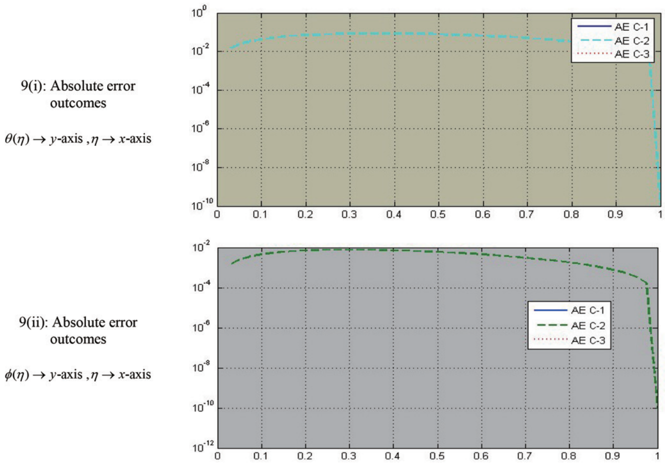

Fig. 9 Comparing the results of Adams and Runge kutta with analyses on absolute error for MHD-PE fluid model, for Scenario 4 of three cases by varying parameter R= 0, 0.5, 1.

5. CONCLUSIONS

The study delivers a complete investigation of the transfer of heat and mass transfer dynamics in the magnetohydrodynamic Powell-Eyring (MHD-PE) fluidic model that displays non-Newtonian fluids' behavior to electromagnetic radiation. The study enables numerically solving the leading partial differential equations (PDEs) using Mathematica's explicit Runge-Kutta method and Adams' numerical solver. This was attained by changing the partial differential equations PDEs into corresponding nonlinear ordinary differential equations ODEs using similarity conversions. The effect of changing important parameters, such as the permeability, fluid, radiation, magnetic field parameter, Lewis, Prandtl, and Eckert numbers, were carefully assessed in the study. This approach made it easier to generate synthetic dataset by using the Adams numerical and Runge-Kutta methods with the help od ND-Solver and analyzing it in MATLAB for performance comparison. The study displayed the efficacy of the proposed MHD-PE fluid model by means of absolute error plots and solution graphs, presenting a clear picture of the complex connection between electromagnetic forces, effect of heat and mass on these fluids. This work delivers a robust structure to understand the performance of MHD-PE fluids, which significantly develops the computational fluid dynamics (CFD) field. To efficiently check the behavior of fluid in a diversity of applications, it highlights how important it is to take qualities of non-Newtonian and electromagnetic properties in fluid flow models.

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