Influence of Chemical and Radiation on an Unsteady MHD Oscillatory Flow using Artificial Neural Network (ANN)

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Abstract: – This paper delves into the intricate interplay between chemical and thermal radiation in the context of an unstable magnetohydrodynamic(MHD) oscillatory flow through a porous medium. The fluid under investigation is presumed to be incompressible, electrically conductive, and radiating with the additional influence of a homogeneous magnetic field applied perpendicular to the channel's plane. Analytical closed-form solutions are derived for the momentum, energy, and concentration equations providing a comprehensive understanding of the system's behavior. The investigation systematically explores the impact of various flow factors, presenting their effects through graphical representations. The governing partial differential equations (PDE) of the boundary layer are transformed into a set of coupled nonlinear ordinary differential equations (ODE) using a closed-form method. Subsequently, an artificial neural network (ANN) is applied to these ODEs, and the obtained results are validated against numerical simulations. The temperature profiles exhibit oscillatory behavior with changes in the radiation parameter (N), revealing insights into the system's dynamic response. Furthermore, the paper uncovers that higher heat sources lead to increased temperature profiles. Additionally, concentration profiles demonstrate a decrease with escalating chemical reaction parameters, with a reversal observed as the Schmidt number (Sc) increases. This study highlights the efficacy of an ANN model in providing highly efficient estimates for heat transfer rates from an engineering standpoint. This innovative approach leverages the power of artificial intelligence to enhance our understanding of complex fluid magnetohydrodynamics and porous media flows.

Key-Words: - MHD, Oscillatory flow, Porous medium, Chemical Reaction, Thermal Radiation, HMT – Heat and Mass Transfer, ANN.

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1 Introduction

There has been a lot of interest in coupled HMT unsteady situations involving chemical reactions in recent decades. The drying process, evaporation of a water body at the surface, and HMT all occur at the same time. This flow application is employed in a wide range of industries. Chemical reactions are employed in a wide assortment of businesses. To begin, businesses use galvanized products to create corrosion-resistant steel. In industry, electrolysis is used to generate pure quality commodities and minerals. Chemical reactions are used in industry to recover minerals from ores. In [1], author contributes to the understanding of MHD effects on oscillatory flow around a semi-infinite plate. In [2], the impact of MHD unsteady oscillatory flow through a porous medium was explored. In [3], the hybrid nanofluid in the presence of thermal radiation was discussed. The impact of chemical and thermal radiation on an oscillatory flow was studied in [4]. The unsteady oscillatory flow with binary chemical reactions was explored in [5]. The unsteady MHD oscillatory casson fluid with chemical and soret effects was discussed in [6]. The heat transfer capabilities of hybrid and traditional nanofluids were compared in [7]. In [8], the viscous dissipation of an unsteady third-grade fluid was studied. In [9], the author explored the dufour effect and emission incorporation for MHD Newtonian fluid. The effect of MHD on an oscillatory couette flow using analytical methods in [10].

Flows through porous media serve a significant role in a variety of applications, including gas and liquid filtering, human breathing, and excretory discharge through porous skin. Because of its significance in soil mechanics, the study of oscillatory flow in a porous channel has received a lot of interest recently. In [11], researchers investigated the effects of chemical processes on oscillatory MHD flow in an asymmetric channel. In [12], authors investigated MHD channel flow through a porous medium – numerical approach. This paper deals with radiative heat and convective cooling.

In [13] examined the augmentation of heat transfer rates using the Monte Carlo trace method. Subsequently, they investigated an alternative approach, Artificial Neural Networks (ANN), and concluded that the computational cost is significantly lower than that of the traditional Monte Carlo Ray Tracing (MCRT) method. In [14] explored heat enhancement using the ANN approach. In [15] delved into the thermos-bioconvection model using computational fluid dynamics (CFD) and artificial intelligence. In [16] employed a CFD machine learning approach to study modeling strategies, reducing computational costs and evaluating the machine learning model. In [17] developed artificial intelligence machine learning approaches for simulating combustion thermal analysis. The results indicated that ANN can be successfully utilized in various heat transfer applications. In [18] investigated the impact of heat generation/absorption in non-Newtonian fluid using the ANN concept.

This research delves into the intricate analysis and enhancement of momentum equation, energy equation, and concentration equation in the realm of fluid dynamics. Accurate modeling and prediction of fluid dynamics are vital in a variety of engineering applications, including aeronautical and environmental sciences.

This research will investigate how a chemical process and heat radiation influence an unstable oscillatory magnetohydrodynamic (MHD) flow in porous media. The governing equations for fluid flow, as well as the required boundary conditions, are solved. The study investigates the effects of several parameters on velocity, temperature, and concentration, with the results shown graphically using MATLAB.

2 Mathematical Formulation

Consider the flow of an oscillatory fluid with magetohydrodynamic (MHD) properties, electrical conductivity, and chemical reactivity through a porous media positioned between two infinite vertical porous plates at a distance 'd'. The channel is oriented with the X-axis vertically and the Y-axis perpendicular to the plane of the plates. Several assumptions have been made:

- All fluid properties, except for density, are considered constant.
- Temperature influences the density property.
- The flow is characterized as unsteady and oscillatory assuming the pressure gradient oscillates at the channel ends.
- The induced magnetic field is deemed insignificant.
- Viscous and Darcy's resistance factors are considered when the permeability of the porous media is constant.
- The governing equations for the flow, under the typical Boussinesq approximation, are provided as follows:

The flow's governing equations are:

Momentum Equation

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + g\beta^*(C - C_0) + \gamma\frac{\partial^2 u}{\partial y^2} - \frac{\sigma {B_0}^2}{\rho}u - \frac{\gamma}{k}u + g\beta(T - T_0) \quad (1)$$

Energy Equation

$$\frac{\partial T}{\partial t} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{1}{\rho C_p}\frac{\partial q}{\partial y} + \frac{Q}{\rho C_p} \quad (2)$$

Concentration Equation

$$\frac{\partial C}{\partial t} = D_M\frac{\partial^2 C}{\partial y^2} - {K_c}'(C - C_0) \quad (3)$$

with the boundary conditions,

$$u = 0,\ T = 0,\ C = 0 \ \text{ on } y = -d/2 \quad (4)$$

$$u = 0,\ T = 0,\ C = 0 \ \text{ on } y = d/2 \quad (5)$$

Radiative heat flux is given by,

$$\frac{\partial q}{\partial y} = 4\alpha^2(T - T_0) \quad (6)$$

Dimensionless variables are,

$\vec{x} = \frac{x}{d}$; $\vec{y} = \frac{y}{d}$; $\vec{u} = \frac{u}{U}$; $Re = \frac{Ud}{\gamma}$; $\theta = \frac{T-T_0}{T_1-T_0}$; $\varphi = \frac{C-C_0}{C_1-C_0}$; $M^2 = \frac{\sigma {B_0}^2 d^2}{\rho\gamma}$; $\vec{t} = \frac{tU}{d}$; $\vec{P} = \frac{Pd}{\rho\gamma U}$; $Da = \frac{k}{a^2}$; $c = \frac{D_M}{Ud}$; $Gr = \frac{g\beta(T_1-T_0)}{\gamma U}d^2$; $Gc = \frac{g\beta^*(C_1-C_0)}{\gamma U}d^2$; $Pe = \frac{Ud\rho C_p}{k}$;

$$N^2 = \frac{4\alpha^2 d^2}{k} \; ; \; K_c = \frac{K_c' d}{U} \; ; \; \alpha = \frac{Qd^2}{K(T_1 - T_0)} \tag{7}$$

3 Solution of the Problem

$$Re\frac{\partial u}{\partial t} = -\frac{\partial P}{\partial x} + \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{k}\right)u + Gr\theta + Gc\varphi \tag{8}$$

$$Pe\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + (N^2 + \alpha)\theta \tag{9}$$

$$\frac{\partial \varphi}{\partial t} = Sc\,\frac{\partial^2 \varphi}{\partial y^2} + K_c\varphi \tag{10}$$

with the boundary conditions,

$$u = 0,\; \theta = 0,\; \varphi = 0 \;\; \text{on } y = -1/2 \tag{11}$$

$$u = 0,\; \theta = 0,\; \varphi = 0 \;\; \text{on } y = 1/2 \tag{12}$$

4 Method of Solution

Assuming pressure gradient for purely oscillatory flow as,

$$-\frac{\partial P}{\partial x} = \lambda e^{i\omega t} \tag{13}$$

Let us assume the solutions for $u(y,t), \theta(y,t)$ and $\phi(y,t)$ be in the form,

$$\left.\begin{aligned} u(y,t) &= u_0(y)e^{i\omega t} \\ \theta(y,t) &= \theta_0(y)e^{i\omega t} \\ \phi(y,t) &= \phi_0(y)e^{i\omega t} \end{aligned}\right\} \tag{14}$$

Substituting (13) and (14) in (8), (9), (10), we obtain

$$\frac{d^2\theta_0}{dy^2} + m_1\theta_0 = 0 \tag{15}$$

$$\frac{d^2\varphi_0}{dy^2} - {m_2}^2\phi_0 = \frac{1}{Sc}\,{m_1}^2\theta_0 \tag{16}$$

$$\frac{d^2u_0}{dy^2} - {m_3}^2 u_0 = -\lambda - Gr\theta_0 - Gc\phi_0 \tag{17}$$

with the boundary conditions,

$$u = 0,\; \theta = 0,\; \varphi = 0 \;\; \text{on } y = -1/2 \tag{18}$$

$$u = 0,\; \theta = 1,\; \varphi = 1 \;\; \text{on } y = 1/2 \tag{19}$$

where $m_1 = \sqrt{N^2 + \alpha - Pei\omega}$, ${m_2}^2 = \frac{K_c + i\omega}{Sc}$ and

$m_3 = S^2 + M^2 + i\omega Re.$

Equations (15), (16) and (17) are solved using equations (18) and (19). we obtain,

$$\theta(y,t) = \frac{sinm_1 y}{sinm_1}\, e^{i\omega t} \tag{20}$$

$$\phi(y,t) = \left[\frac{sinhm_2 y}{sinhm_2} + \frac{1}{Sc}\,\frac{m_1}{({m_1}^2 + {m_2}^2)}\,\frac{sinhm_2 y}{sinhm_2} - \frac{1}{Sc}\,\frac{m_1}{({m_1}^2 + {m_2}^2)}\,\frac{sinhm_1 y}{sinhm_1}\right] e^{i\omega t} \tag{21}$$

$$u(y,t) = \left\{\begin{aligned} &\frac{\lambda}{{m_3}^2}[1 + sinhm_3(1-y) + 2sinhm_3 y] \\ &- \frac{Gr}{{m_1}^2 + {m_3}^2}\left[\frac{2sinhm_3 y}{sinhm_3} - \frac{2sinhm_3(1-y)}{sinhm_3} - \frac{sinhm_1 y}{sinhm_1}\right] \\ &- \frac{1}{Sc}\frac{m_1}{({m_1}^2 + {m_2}^2)}\left[\begin{aligned} &\left(1 + \frac{1}{({m_1}^2 + {m_3}^2)}\right) 2sinhm_3 y \\ &- \frac{sinhm_2 y}{({m_2}^2 + {m_3}^2)sinhm_2} - \frac{sinhm_1 y}{({m_1}^2 + {m_3}^2)sinhm_1} \end{aligned}\right] \\ &- \frac{Gc}{{m_2}^2 + {m_3}^2}\,\frac{1}{sinhm_2} \end{aligned}\right\} e^{i\omega t} \tag{22}$$

5 Results and Discussion

To investigate the effects of chemical and thermal diffusion on the radiative oscillatory MHD flow are graphically depicted against y for various physical parameters such as Peclet number, Magnetic number, Schmidt number, chemical process parameter and so on.

Figure 1 depicts the fluid temperature for various levels of thermal radiation. It is obvious that an increase in heat radiation raises the temperature. This is because increasing the radiation parameter causes heat energy to be released into the fluid. This is consistent with the radiation parameter's fundamental physical behavior. As the radiation parameter value increases, so does the thermal boundary layer, which has an increasing effect on temperature. We discovered that increasing thermal radiation thickens the thermal boundary layer, which improves heat transfer. As the thermal radiation parameter is increased, the temperature distribution improves. Thermal radiation values increase the heat of the working fluid more, raising the temperature and thermal boundary layer thickness. The thermal radiation parameter does not affect the concentration distribution in flow.

Figure 2 depicts the effect of the Peclet number on temperature. The Peclet number is defined as the ratio of advective transport to diffusive transport. A low Peclet number (Pe < 1) indicated that diffusion is dominant over advection. In such cases, the temperature within the system is effectively smoothed out by diffusion. A high Peclet number (Pe >1) implies that advection is dominant and the effects of diffusion are negligible. In this situation, the transport is mainly driven by the bulk motion of fluid. It demonstrates that temperature rises with increasing Peclet number.

Figure 3 displays the fluid velocity for various magnetic parameter values. Increasing magnetic parameters reduces the fluid velocity. This is due to the increase in resistive type force known as Lorentz force caused by the transverse magnetic field on an electrically conducting fluid and increasing magnetic field values, which causes fluid velocity to slow down.

The effect of the chemical reaction parameter is highly important in the concentration field. Figure 4 demonstrates that as the chemical process is accelerated, the fluid concentration decreases. This is because boosting the chemical process speeds up the reactant rate process on the flow, lowering the concentration of the reacting species. Interfacial MT is accelerated by the chemical process. The chemical reaction decreases local concentration while increasing concentration gradient and flow. The chemical reaction parameter has little to no effect on the flow's temperature profile. The effect of Schmidt number on concentration profiles is depicted in Figure 5. The concentration profiles grow consistently as the Schmidt number Sc increases.

This research investigates the combined influence of chemical and thermal radiation on oscillatory MHD flow in a porous media containing HMT. Converting the controlling PDE to an ODE offers exact solutions. MATLAB is used to visually analyze velocity, temperature, and concentration profiles for a variety of flow parameters.

The recent analysis found that velocity rises with decreasing magnetic field. Temperature profiles fluctuate as radiation parameter N changes. It has also been discovered that temperature profiles grow in proportion to the heat source. Concentration patterns drop as chemical reaction parameters grow, but reverse as Schmidt number Sc increases. It is also found that temperature rises when the flow parameter Peclet number increases.

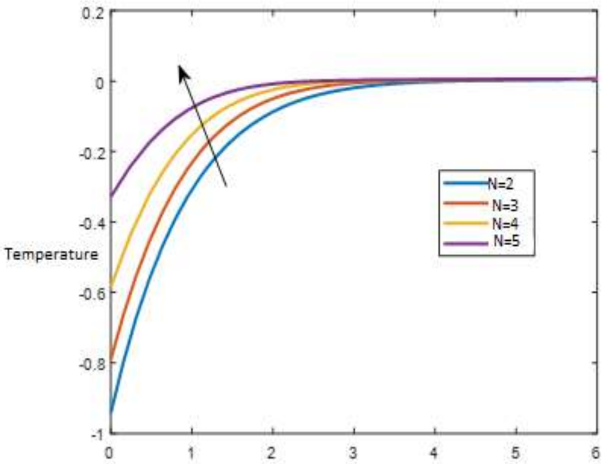

Fig. 1: Impact of thermal radiation on temperature

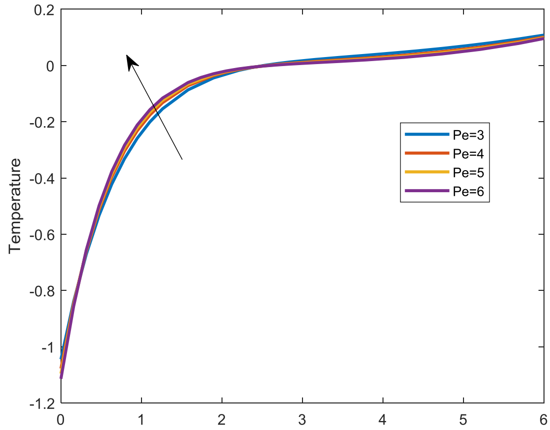

Fig. 2: Impact of Peclet number on temperature

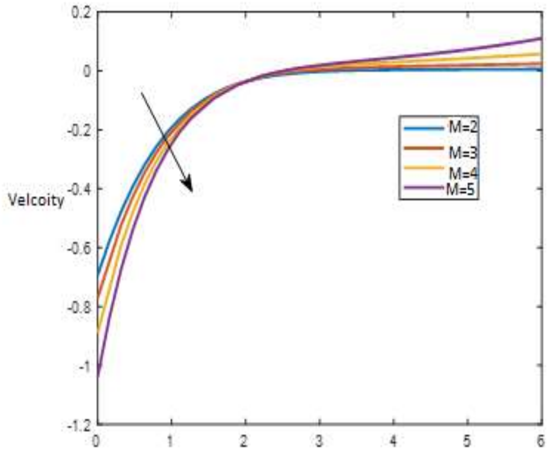

Fig. 3: Impact of Magnetic field on Velocity

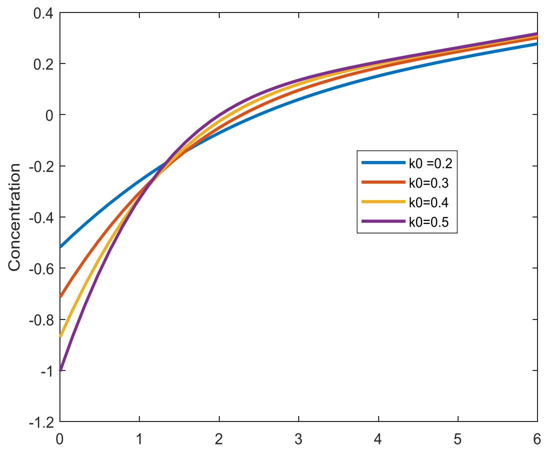

Fig. 4: Impact of chemical reaction on concentration

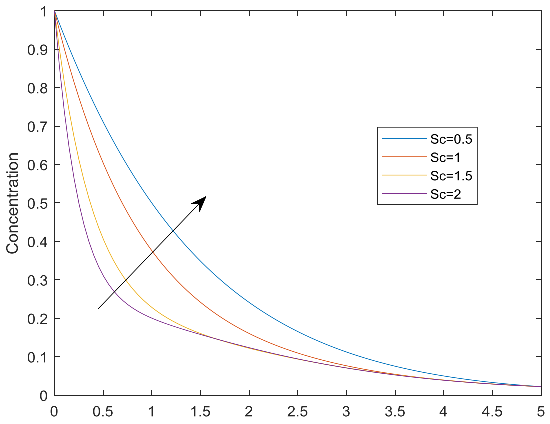

Fig. 5: Impact of Schmidt number on concentration

6 Modelling - Artificial Neural Network

Artificial neural networks, inspired by biological networks of neurons, are designed to perform specific tasks such as grouping, classification, and pattern recognition. The activation of a neuron is determined by weights, and the output of an artificial neuron is computed using another function.

ANN have found widespread applications across various domains due to their ability to model complex relationships and learn patterns from data. Here are some practical applications of the ANN Method: Image and Speech Recognition, Financial Forecasting, Healthcare Diagnostics, Autonomous Vehicles, Gaming and Virtual Reality, and so on. These applications showcase the versatility and effectiveness of ANN in solving complex problems and improving decision-making processes across diverse industries.

This study employs a multi-layer feed-forward neural network with the Back Propagation training algorithm. The multi-layer perception consists of at least three layers: an input layer, an output layer and one or more hidden layers. Weights are adjusted through the Back Propagation training method to minimize the difference between expected and actual results.

The construction and training of the artificial neural network structures took place in MATLAB. Back Propagation training was implemented in a feed-forward network with one hidden layer. The training process utilized 70% of the entire dataset, while 15% was allocated for validation, and another 15% was reserved for evaluating the model's output.

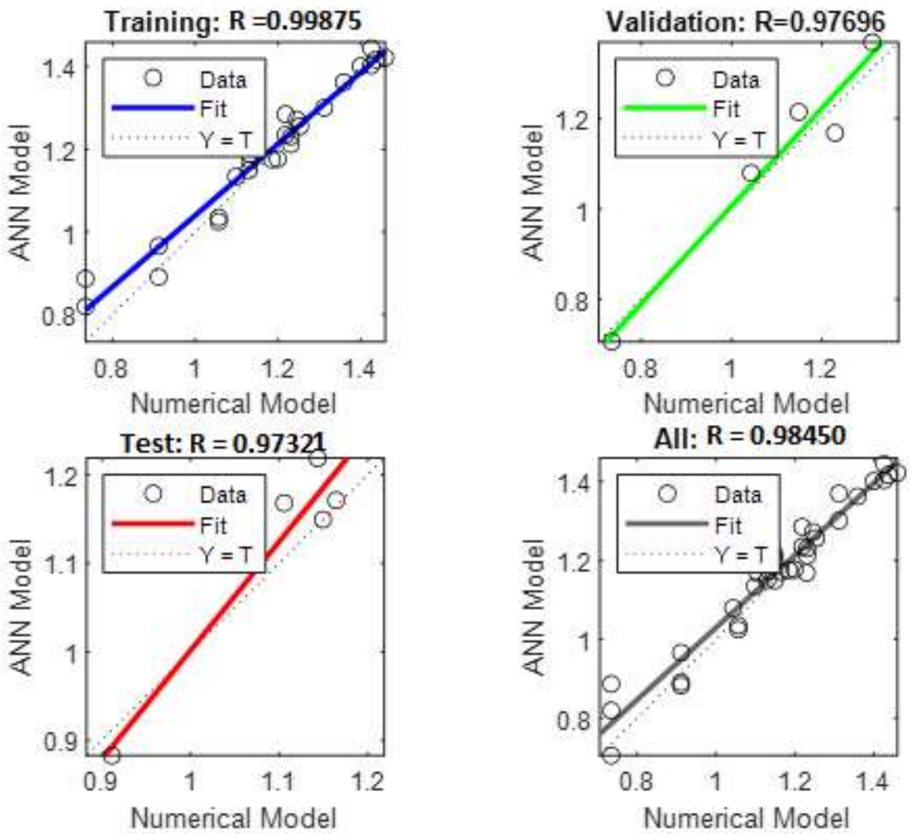

Fig. 6: Graphical Representation of skin friction coefficients

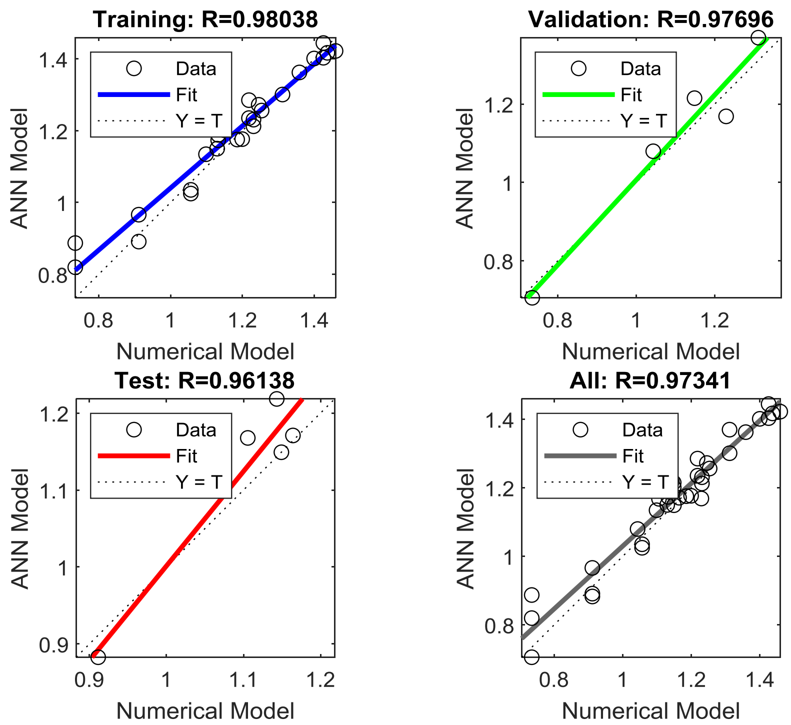

Fig. 7: Graphical representation of Nusselt number coefficient

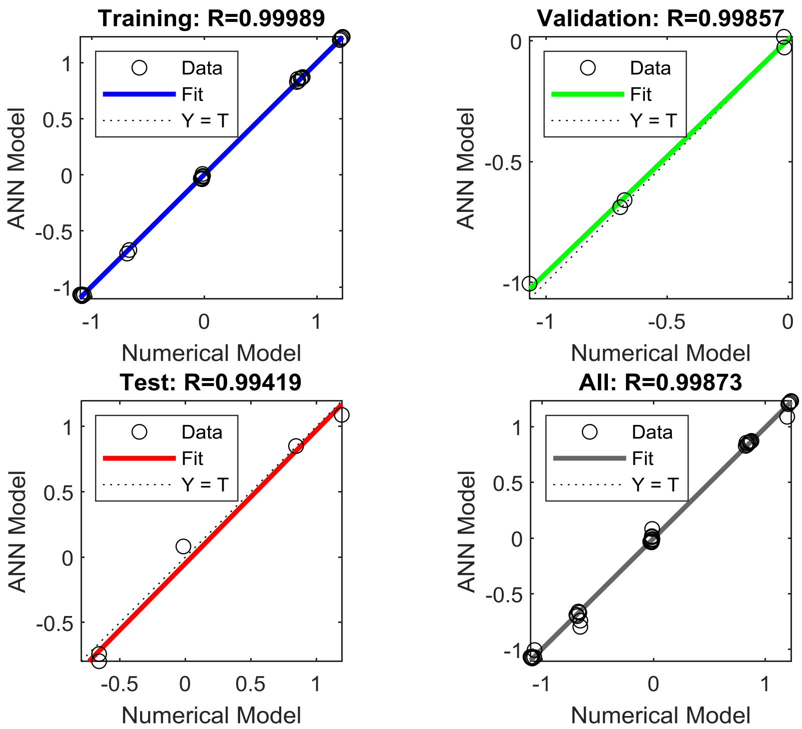

Fig. 8: Graphical representation of Sherwood number coefficient

The artificial neurons employed a sigmoid function as their activation function, with training conducted over a fixed number of epochs. For the prediction of skin friction, Nusselt number and Sherwood number three separate ANN models were trained, tested, and validated using a total of 80 numerical results. In each case, the initial 50 data sets were allocated for training, the subsequent 15 for validation, and the remaining sets for testing the model's outcomes. The performance of the suggested ANN models on the training, validation, and test sets for skin friction, Nusselt number, and Sherwood number is illustrated in Figure 6, Figure 7 and Figure 8 respectively.

Figure 6, Figure 7 and Figure 8 showcase the performance of the ANN models across training, validation, and test sets focusing on skin friction coefficient, Nusselt number, and Sherwood number. Remarkably, the ANN models exhibited a high degree of accuracy, successfully capturing the intricate relationships between input and output variables. The results obtained from the ANN models closely align with the numerically derived values.

7 Conclusion

This research investigates the combined influence of chemical and thermal radiation on oscillatory MHD flow in a porous media containing HMT. Converting the controlling PDE to an ODE offers exact solutions. MATLAB is used to visually analyze velocity, temperature, and concentration profiles for a variety of flow parameters.

The recent analysis found that,

- Velocity rises with decreasing magnetic field.
- Temperature profiles fluctuate as radiation parameter N changes. It has also been discovered that temperature profiles grow in proportion to the heat source.
- Concentration patterns drop as chemical reaction parameters grow, but reverse as Schmidt number Sc increases. It is also found that temperature rises when the flow parameter Peclet number increases.

In addition to the above conclusion, we found the following agreement using the ANN Model.

The current study successfully employs the ANN technique to simulate HMT in the MHD chemical and thermal radiation flow through a porous medium. The ANN structure was trained, validated, and tested in the MATLAB environment. The artificial neural network methodology is a viable way for predicting the heat transfer MHD flow of an inclined stretching/shrinking sheet, according to the results and comparison analysis. The ANN model's prediction of skin friction, Nusselt number, and Sherwood number fits the standard numerical data well. The ANN model is a valuable tool and a potential alternative to traditional time-consuming numerical approaches since it offers quick, precise, and trustworthy results.

8 Future Work

Development of Hybrid Models: Explore the development of hybrid models that combine traditional mathematical models for fluid dynamics, MHD, chemical reactions, and radiation with ANN based models. This could improve the accuracy and efficiency of predictions.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- R.Kavitha, carried out Conceptualization, Investigation, Methodology and Software.
- M.Mahendran was responsible writing-original draft, writing-review and editing.

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Conflict of Interest

The authors have no conflicts of interest to declare.

Data availability

The data used to support the findings of this study are included within the article. Further data or information is available from the author upon request.