Hybrid Nanofluid Dynamics in Engine Oil: A Multilayer Perceptron Approach to Heat and Mass Transfer with Chemical and Thermo-Diffusion Effects

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ABSTRACT

Background: The study investigates the interaction of MoS_2 and ZnO nanoparticles in engine oil, aiming to enhance the thermal and tribological properties of lubricants. It explores the potential of a hybrid nanofluid to improve heat and mass transfer efficiency, particularly in scenarios involving a stretched wall, while accounting for the effects of chemical reactions and thermo-diffusion.

Methodology: The governing nonlinear partial differential equations describing the flow dynamics are transformed into a system of nonlinear ordinary differential equations using appropriate similarity transformations. These equations are subjected to relevant boundary conditions and solved using the MATLAB Bvp4c package.

Core findings: Numerical computations were conducted to evaluate the behavior of a hybrid nanofluid system. Key parameters included the magnetic parameter ($0 \leq M \leq 2$), Soret number ($0.2 \leq Sr \leq 1$), Casson fluid parameter ($0 \leq \beta \leq 3$), Eckert number ($0 \leq Ec \leq 1$), and hybrid nanolubricant parameters ($0 \leq \phi_2 \leq 0.6$). Results were validated by comparison with another numerical method, confirming the feasibility of the solution.

Validation: The proposed multi-layer perceptron (MLP) model has high precision in predicting the skin friction coefficient, reaching 99.31% for case 1 and 98.78% for case 2. By addressing outliers and influential data points, the model achieves 90% accuracy for predicted and historical values, establishing its effectiveness for applying tetra-hybrid nanofluids.

Applications: An artificial neural network (ANN) optimized the hidden layer neuron count, with the dataset split into training, testing, and validation to ensure robust performance and prevent overfitting. This hybrid nanofluid model, utilizing MoS_2 and ZnO nanoparticles, has applications in lubrication, cooling systems, and oil thermal recovery, particularly in aerospace and defense, where high-performance lubricants are vital for reliability and safety under extreme conditions.

Keywords: Hybrid nanofluid; hybrid nanolubricant; multi-layer perceptron; multiple linear regression; thermo-diffusion effect.

1. INTRODUCTION & OBJECTIVE

Researchers are exploring new nanoparticle blends and their thermal transfer properties to enhance the conductivity of base fluids, aiming to improve nanofluid performance. These blends are promising for modern engineering due to their potential to boost heat transfer efficiency and thermal stability. According to M sajid and HM Ali (1) increasing temperature and concentration enhances thermal conductivity, while careful selection of hybrid nanoparticles is essential for maintaining stability in hybrid nanofluids. This study focuses on analyzing the heat and mass transfer characteristics of a Casson hybrid nanofluid (MoS_2 + ZnO) in engine oil over a stretched surface, accounting for chemical reactions and thermo-diffusion effects. The MoS_2 + ZnO hybrid nanofluid was chosen for its excellent energy conversion properties. The results from Multiple Linear Regression (MLR) are compared with numerical results and used to train an Artificial Neural Network (ANN) to generalize outcomes for specified parameters (2).

2. FLOW ANALYSIS

A two-dimensional Casson hybrid nanofluid flow is analyzed, focusing on mass diffusion and heat transport at the interface of a porous material, under the influence of an applied magnetic field and varying viscosity. Radiative heat transfer and activation energy are incorporated into the energy and concentration equations, respectively. The flow behavior of the hybrid nanofluids is described based on their thermophysical properties.

3. MATERIALS AND METHODS

The key thermophysical properties of the nanofluids and base fluids are taken into account to solve the relevant equations, where nonlinear partial differential equations are converted into ordinary differential equations using a similarity transformation (3). To achieve an approximate numerical solution, the MATLAB Bvp4c technique is applied as the numerical method.

4. PHYSICAL ASPECTS AND SIGNIFICANCE RESULTS

4.1. NUMERICAL PROCEDURE

Figures 1 and 2 show two sets of results: one for the single nanolubricant (MoS_2/engine oil) and the other for the hybrid nanolubricant (MoS_2/engine oil + ZnO). Figure 1 illustrates the impact of velocity on the magnetic parameter, while Figure 2 depicts the influence of concentration on the Soret number.

M	K_P	β	-f''(η)
0.0	0.5	0.5	0.7322
0.5			0.8241
1.0			0.9068
1.5	0.1		0.9122
	0.3		0.9480
	0.5		0.9826
		0.1	0.5132
		0.2	0.6948
		0.3	0.8176

Pr	Q	Ec	-θ'(η)
7.0	0.01	0.1	1.5066
8.0			1.6189
10.0			1.8224
7.0	0.02		1.4892
	0.05		1.4362
	0.09		1.3629
		0.15	1.4219
		0.2	1.3372
		0.25	1.2525

Sc	Sr	Kr	-ϕ'(η)
2.5	0.8	0.2	0.5830
3.0			0.6366
3.5			0.6844
0.4	0.5		0.4228
	0.6		0.4705
	0.7		0.5182
		0.3	0.6144
		0.4	0.6575
		0.5	0.6964

Table 1. Results for skin friction. **Table 2**. Results for Nusselt Number **Table 3**. Results for sherwood number

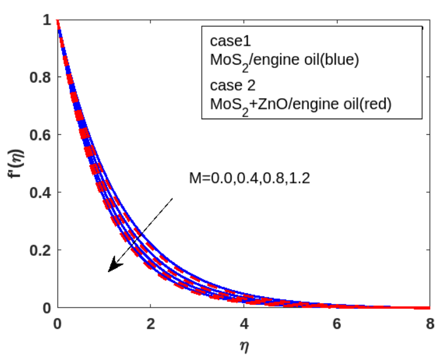

Figure 1. Impact of M on velocity f'(η)

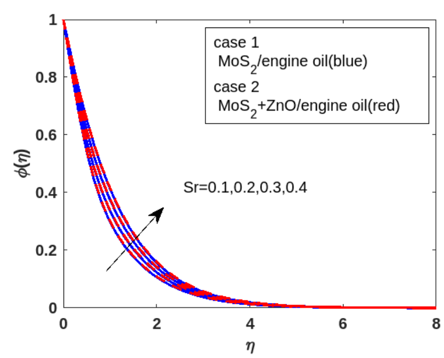

Figure 2. Impact of Sr on Concentration ϕ (η)

Figure 1 shows that as the magnetic parameter M increases, the nondimensional linear speed f′(η) decreases for both the single and hybrid nanolubricants. This slowdown is due to the stronger Lorentz force opposing the flow with higher M. Additionally, it was observed that the hybrid nanofluids exhibited a higher temperature compared to the other nanofluids. Figure 2 shows that an increase in the Soret number raises the concentration profile. This is because a higher Soret number leads to a steeper temperature gradient, which enhances convection flow and thus increases the concentration.

4.2. MACHINE LEARNING

Machine learning systems leverage data to detect patterns, make predictions, and enhance their performance over time. In this study, Multiple Linear Regression (MLR) is employed to gather datasets using numerical values from Tables 1-3, which were generated with MATLAB. [(4)](#).

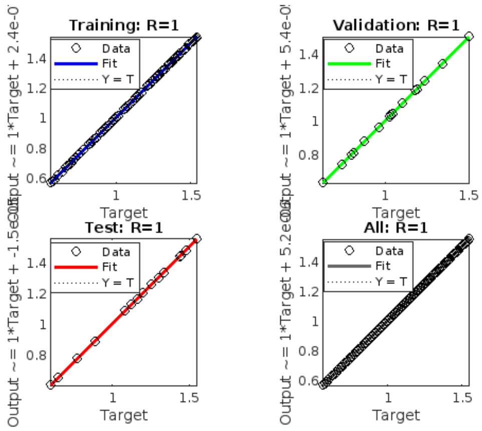

Figure 4. Trained ANN output of Skin friction

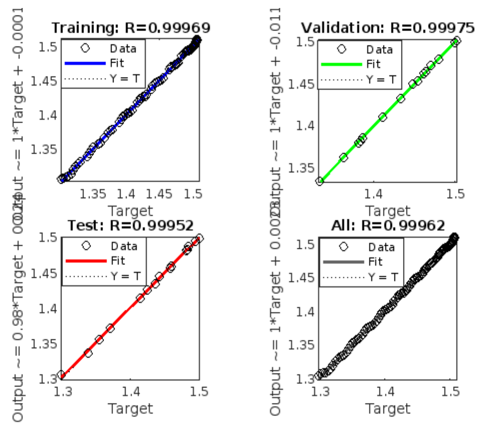

Figure 5. Trained ANN output of Nusselt number

These MLR-derived values are then input into an Artificial Neural Network (ANN) model to determine results for skin friction, Nusselt number, and Sherwood number. Figures 4 and 5 display the regression plots obtained from the Multi-Layer Perceptron (MLP) analysis.

5. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

A Casson fluid model is used to investigate mass and heat transfer across a stretching sheet, with a focus on the improved thermal efficiency of hybrid nanolubricants. Comparisons are made between the flow and thermal properties of these hybrid nanolubricants and those of a standard nanolubricant (MoS_2/engine oil).

1. The velocity profile decreases with increasing values of the magnetic parameter M.
2. The temperature profile rises with higher values of the Eckert number Ec. This is because higher Ec indicates more significant effects of viscous dissipation on temperature.
3. The concentration profile increases with a higher Soret number Sr, which intensifies the temperature gradient-induced concentration gradient. It decreases with higher Schmidt number Sc and permeability parameter Kr, indicating lower diffusion rates and reduced material transport.

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