PINN-based Computational Analysis of non-Newtonian Fluid Flow and Heat Transfer

Himanshu Upreti[*] **Ziya Uddin, Mohd Vaseem**
School of Engineering and Technology
BML Munjal University
67th Milestone, NH 48, Kapriwas, Haryana 122413
himanshu.upreti@bmu.edu.in

Abstract

Background: The study of non-Newtonian fluids, especially tangent hyperbolic fluid (THF), is important for many industrial and engineering applications due to their non-linear behavior. The Cattaneo-Christov heat flux (CCHF) model, which incorporates the time-lag effect, offers a more precise representation of heat transfer than Fourier's law, which is usually employed in many studies. The flow across plates with variable thickness is critically significant due to its usage in heat exchangers and the automotive sector, where it enhances engine efficiency by regulating the fluid flow.

Purpose: This study analyses the flow characteristics and heat transfer behaviour of a THF over a plate with variable thickness, employing the CCHF model. The system is heated externally by a space and temperature-dependent heat source; and the fluid flow is induced by the stretching of the surface with velocity u_w (x) in both directions of the x-axis, while free stream velocity is u_e (x). And, leverage the physics-informed neural network (PINN) to quickly solve the governing equations and learn how parameters such as the Weissenberg number (We), thermal relaxation (τ) , index parameter (n), and thickness parameter (α) affect the flow of fluids.

Methodology: A similarity transformation transforms the governing fluid flow equations, initially written as partial differential equations (PDEs), into ordinary differential equations (ODEs). The first third-order ODE explores the momentum components of the flow, capturing the velocity profile and flow dynamics. The second-order ODE pertains to energy transmission, specifying the temperature distribution and heat transfer characteristics of the system. The Physics-Informed Neural Network (PINN) approach then solves these ODEs along with the boundary conditions. To implement PINN, we use two separate neural networks, each with four hidden layers and 30 neurons, to approximate the model's solution. We generate a total of 5,000 collocation points for training and optimize the networks using the Adam optimizer and the Tanh activation function. And, to demonstrate the accuracy of the applied methodology, we compared results with published literature, demonstrating excellent accuracy.

Novelty: This study integrates the CCHF model with a THF flow over a non-uniform plate, and it leverages a PINN, an unsupervised machine learning technique, to solve the complex flow and heat transfer problem. The novelty lies in applying PINNs to this type of non-Newtonian fluid flow, allowing for efficient and accurate predictions compared to traditional numerical methods.

Findings: The findings demonstrate that a 0.3 unit rise in We results in a 3.06% reduction in the local Nusselt number (LNN). Moreover, the temperature of the fluid escalates although its velocity diminishes as We ascend. In contrast, the

[*]Use footnote for providing further information about author (webpage, alternative address)—*not* for acknowledging funding agencies.

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fluid's temperature diminishes with an elevated τ value, whereas LNN exhibits a 0.90% increase. An increase in the plate's thickness (α) leads to heightened fluid velocity and temperature. Altering index parameter from linear to quadratic configuration, yields a 20.51% increase in LNN.

Keywords: Unsupervised ML; Tangent hyperbolic fluid; Cattaneo-Christov model; PINN