Multi-objective Physics-Informed Neural Networks for Hybrid Nanofluid Flow and Heat Transfer in Eccentric Cylinder

Sai Ganga
BML Munjal University
Gurugram, Haryana, India.
sai.ganga.21pd@bmu.edu.in

Ziya Uddin *
BML Munjal University
Gurugram, Haryana, India.
ziya.uddin@bmu.edu.in

Background: The study of peristaltic transport over an eccentric cylinder finds applications across diverse fields, one of the application is endoscope. The endoscope is a very important tool used for determining real reasons responsible for many problems in the human organs in which the fluid are transported by peristaltic pumping. Understanding the velocity and variation of pressure gradient is essential during insertion of medical devices into human body.

Purpose: This research explores the use of physics-informed neural networks (PINNs) to simulate the peristaltic flow of a hybrid nanofluid within an eccentric cylindrical domain, incorporating heat transfer effects. The approach uses a multi-objective loss function to overcome the challenge of incomplete boundary data by incorporating extra physical information. This addition ensures the model achieves accurate and reliable predictions. The adaptability of PINNs to model intricate systems makes them particularly suitable for problems of interest in biomedical engineering.

Methodology: We mathematically formulate the peristaltic flow of a hybrid nanofluid within an eccentric cylinder into a set of coupled partial differential equations (PDEs) and convert them into non dimensional form with the help of non dimensional variables and parameters. We employ PINNs to solve these set of equations. The residual of these PDEs are incorporated as the loss function. In the mathematical formulation, the boundary condition for pressure is not provided. To enhance the model with additional information, a combination of the mean volume flow equation and the instantaneous volume flow rate is included as a term in the loss function. We utilize three different neural networks to approximate three unknown solution. Adam optimizer with decaying learning rate was utilized for optimization. Gaussian wavelet was used as the activation function.

Novelty: This study explores the use of physics-informed neural networks (PINNs) to model peristaltic transport through an eccentric cylinder, a problem traditionally addressed using analytical approximation methods. While such methods provide good approximations, they involve complex and tedious mathematical calculations, which become increasingly challenging as the problem's complexity grows. By contrast, PINNs offer a flexible framework that can easily adapt to these scenarios without the need for extensive derivations. This work demonstrates the potential of PINNs to provide reliable predictions for problems with missing initial/boundary conditions.

Findings: The proposed methodology has been validated by comparing the results with available literature for two limiting cases: one without peristaltic pumping and the other without heat transfer. The validation showed consistent and reliable outcomes. Additionally, the study examines the impact of various flow parameters, such as the Grashof number, heat source parameter, and hybrid nanofluid concentration, on velocity and temperature profiles. The results demonstrate the effectiveness of PINNs in addressing challenges relevant to biomedical engineering, showcasing their potential for application across a broad spectrum of fluid dynamics problems.

Keywords: PINNs, Peristaltic transport, Eccentric cylinder

*Corresponding author: ziya.uddin@bmu.edu.in

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