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Fractional-order modeling for convective flow study in porous enclosure: Application of DNN

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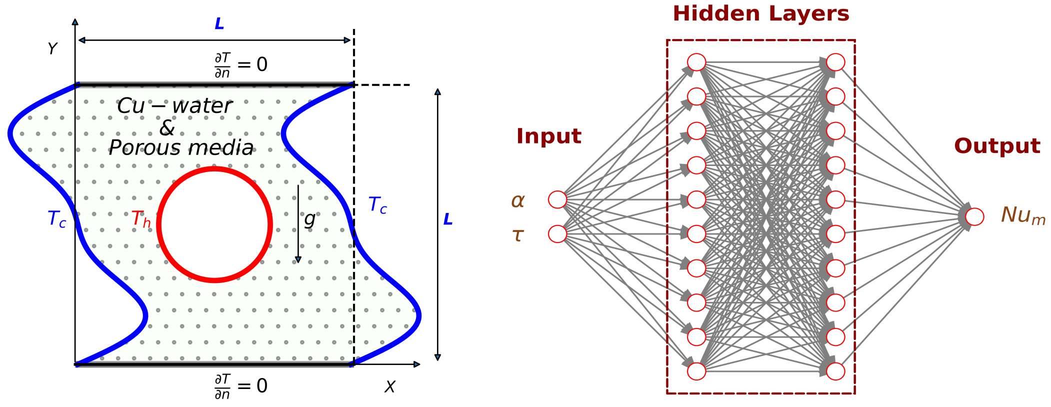
Abstract

This study presents a comprehensive analysis of the fractional order time-evolution phases of fluid flow and thermal transport within a wavy square enclosure containing a circular cylinder. The enclosure is filled with porous material and saturated with Cu-water nanofluid. Further, the Darcy-Brinkman-Forchheimer based mathematical model is used to simulate the momentum transport in porous enclosure. The fractional governing equations is formulated by substituting the time derivatives term in the momentum and energy equations with the Caputo time derivative term. The numerical simulations are carried out using penalty finite element method and fractional time derivative term is estimated using L1-scheme. The results are presented by streamlines and isotherms contours along with plots for mean Nusselt number (Nu_m) variations. This study also employs a deep neural network (DNN) to predict the Nu_m profile for new fractional order parameter (α). The Comparison of FEM vs DNN results is also shown.
Keywords: Porous media, fractional derivative, penalty finite element method, deep neural network.

1 Introduction and objective

Fractional calculus has gained significant importance due to its wide-ranging applications across various fields of science and engineering such as- fluid mechanics [3], rheology [1], bio-engineering [4], Reservoir Engineering, and mathematical physics. The fractional derivatives possess unique non-local and hereditary properties, making them particularly valuable for modeling complex systems with memory effects and spatial interactions. In recent years, the application of fractional calculus in porous media has garnered significant attention from researchers due to its effectiveness in modeling anomalous diffusion and non-local transport phenomena [2, 5]. Time-fractional models, in particular, have emerged as powerful tools for capturing the complex temporal dynamics inherent in porous media. These models provide a more accurate framework for predicting long-term fluid flow and thermal transport interactions. However, their primary challenge lies in the computational cost, as fractional models are often computationally demanding. Now a days the use of artificial neural networks (ANNs) becoming significant because they have demonstrated exceptional computational power, making deep learning adaptable to a wide range of scientific and industrial domains. The intricate structure of neural networks enables them to model complex relationships between input data and desired outcomes effectively.
In view of this, present study employs a time-fractional model to study the time evolution phases of fluid flow and thermal transport phenomena. The study explores the effect of wide range of fractional order parameter ($0 < \alpha < 1$) on flow characteristics and thermal behavior. the computed results are presented by means of contour variation of streamlines, isotherms and Nu_m plots. Further, the deep neural network technique is employed to test and predict the mean Nusselt number profile for new fractional order parameters. The results show that the implementation of DNNs save the computational time and are able to predict the results with maximum accuracy.



(a) (b)

Figure 1: (a) Schematic diagram of physical domain and (b) Representation of deep neural network.

2 Results

The mean Nusselt number profile for different α values is shown in fig. 2

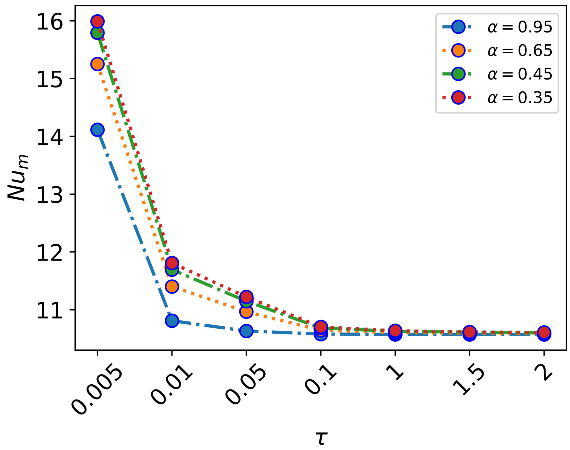


Figure 2: Nu_m variation for different α and τ at $Ra = 10^6$, $Da = 10^{-2}$, and $\epsilon = 0.4$

References

[1] GW Scott Blair, BC Veinoglou, and JE Caffyn. Limitations of the newtonian time scale in relation to non-equilibrium rheological states and a theory of quasi-properties. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, 189(1016):69–87, 1947.

[2] Hamid Karani, Majid Rashtbehesht, Christian Huber, and Richard L Magin. Onset of fractional-order thermal convection in porous media. *Physical Review E*, 96(6):063105, 2017.

[3] Vladimir V Kulish and José L Lage. Application of fractional calculus to fluid mechanics. *J. Fluids Eng.*, 124(3):803–806, 2002.

[4] RL Magin. Fractional calculus in bioengineering begell house publishers. *Inc., Connecticut*, 2006.

[5] Deepika Parmar, BV Rathish Kumar, SVSSNVG Krishna Murthy, and Sumant Kumar. Numerical study of entropy generation in magneto-convective flow of nanofluid in porous enclosure using fractional order non-darcian model. *Physics of Fluids*, 35(9), 2023.