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Full length article

Heat transfer analysis of unsteady graphene oxide nanofluid flow using a fuzzy identifier evolved by genetically encoded mutable smart bee algorithm

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ABSTRACT

In the current research, the unsteady two dimensional Graphene Oxide water based nanofluid heat transfer between two moving parallel plates is analyzed using an intelligent black-box identifier. The developed intelligent tool is known as evolvable evolutionary fuzzy inference system (EE-FIS) which is based on the integration of low-level fuzzy programming and hyper-level evolutionary computing concepts. Here, the authors propose the use of a modified evolutionary algorithm (EA) which is called hybrid genetic mutable smart bee algorithm (HGMSBA). The proposed HGMSBA is used to evolve both antecedent and consequent parts of fuzzy rule base. Besides, it tries to prune the rule base of fuzzy inference system (FIS) to decrease its computational complexity and increase its interpretability. By considering the prediction error of the fuzzy identifier as the objective function of HGMSBA, an automatic soft interpolation machine is developed which can intuitively increase the robustness and accuracy of the final model. Here, HGMSBA-FIS is used to provide a nonlinear map between inputs, i.e. nanoparticles solid volume fraction (ϕ), Eckert number (Ec) and a moving parameter which describes the movements of plates (S), and output, i.e. Nusselt number (Nu). Prior to proceeding with the modeling process, a comprehensive numerical comparative study is performed to investigate the potentials of the proposed model for nonlinear system identification. After demonstrating the efficacy of HGMSBA for training the FIS, the system is applied to the considered problem. Based on the obtained results, it can be inferred that the developed HGMSBA-FIS black-box identifier can be used as a very authentic tool with respect to accuracy and robustness. Besides, as the proposed black-box is not a physics-based identifier, it frees experts from the cumbersome mathematical formulations, and can be used for advanced real-time applications such as model-based control. The simulations indicate that the gradient of Nu has a direct nonlinear relation with the values of ϕ and Ec. It is also observed that an increase in the value of S decreases the value of Nu.

1. Introduction

Nowadays, investigating the characteristics of squeezing flows between parallel disks has become an interesting research topic, and has absorbed an increasing interest of researchers [30,33]. The main reason of such a remarkable interest lies in the fact that it occurs in many industrial applications such as polymer processing, compression, injection modeling, transient loading of mechanical components and the squeezed films in power transmission [1,2]. For the first time, the remarkable work on that topic under lubrication approximation was conducted in Ref. [3]. Thereafter, a seminal theoretical analysis for squeezing flow of power law fluid between parallel disks was performed by Leider and Bird [4]. In spite of importance and practical implications of the squeezing flows between parallel disks, researchers of mechanical fluid society have not had a sensible vision regarding its phenomenological properties. However, after proposition and development of advanced computational approaches, the engineers have been enabled to perform some practical analyzes which in turn have provided them with sufficient information regarding the physical behavior of the phenomenon.

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Nomenclature

A, B	constant parameter of solid volume fraction
C	dimensionless thermal conductivity
Ec	Eckert number
$f(\eta)$	dimensionless velocity
k	thermal conductivity
Nu	Nusselt number
P	pressure term
Pr	Prandtl number
S	moving parameter
T	temperature
T_H	temperature at upper plate
u	velocity component along x-axes
v	velocity component along y-axes
x	Cartesian coordinate in x-direction
y	Cartesian coordinate in y-direction

Greek symbols

$\alpha(t)$	half the distance between two plates
ρ	density
φ	solid volume fraction
μ	viscosity coefficient
η	dimensionless parameter
ν	kinematic viscosity
$\theta(\eta)$	dimensionless temperature

Subscripts

nf	nanofluid
f	fluid
s	nano solid particles

In recent decades, by taking the advantages of advanced numerical methods, a wide range of researches have been conducted on analyzing the squeezing flows between two parallel plates [5]. Sherwood [6] analyzed the squeeze flow of fluid in the gap between non-parallel circular plates of radius R. Hamza [7] used analytical and numerical techniques to study the combined effects of the magnetic forces and the centrifugal inertial forces on the velocity profiles as well as the load capacity and the torques that fluid exerts on the surfaces. Hamza and Macdonald [8] used numerical finite difference technique to study the two-dimensional squeezed flow between two parallel plates. Singh et al. [9] investigated the effects of squeezing flow in a channel with moving boundaries in the perpendicular direction to their surfaces. Islam et al. [10] studied the axisymmetric squeezing flow in a channel with porous medium using numerical method called differential transform method. Munawar et al. [11] analyzed the squeezing flow in stretching porous walls at the presence of magnetic field. They solved the governing equations with a numerical technique known as shooting method. Hatami and Ganji [38] studied the heat transfer and nanofluid flow in suction and blowing process between parallel disks in the presence of variable magnetic field. Domairry et al. [40] used DTM-Pade method for investigating the squeezing Cu–water nanofluid flow analysis between parallel plates. Hatami and Ganji [41] took the advantage of numerical and analytical methods to study the natural convection of sodium alginate non-Newtonian nanofluid between two vertical flat plates. Malvandi et al. [31] reduced the partial differential equations derived from slip effects of unsteady stagnation point flow of a nanofluid over a stretching sheet to ordinary equations and solved them using Range–Kutta–Fehlberg solver.

Generally, the results of the abovementioned investigation have brought the researchers to the conclusion that common heat transfer fluids such as water, ethylene glycol, and engine oil have limited heat transfer capabilities due to their low heat transfer properties. By revealing the limitations behind the use of conventional fluids, researchers have focused on some advanced strategies to tackle the practical diminishments and enhance the thermal conductivity of fluids [32,35–37,39,42,43].

Without any doubt, the enhancement in thermal conductivity of conventional fluids via suspensions of solid particles is one of the most important modern developments in engineering technology which aims at increasing the coefficient of heat transfer [34]. The thermal conductivity of solid metals is higher than the base fluids, so the suspended particles are able to increase the thermal conductivity and heat transfer performance. Choi and Eastman [12] were probably the first researchers to combine a mixture of nanoparticles and base fluid, which they subsequently termed a nanofluid. After the proposition of the concept of nanofluid, several numerical and experimental efforts have been made to analyze its properties. Das [13] engaged the numerical tools to study the temperature dependence of thermal conductivity enhancement for nanofluid. Mohammadian et al. [14] used a three-dimensional conjugate heat transfer model to numerically investigate the laminar forced convection and entropy generation in a counter flow micro-channel heat exchanger including parallel plates with working Al_2O_3–water nanofluid. Kleinstreuer and Feng [15] proposed a novel thermal conductivity model for nanofluid flow to study the characteristics of nanofluid in parallel-disk system. Azimi et al. [16] obtained an analytic solution for an unsteady nanofluid squeezing flow with suction and injection effects using Galerkin optimal Homotopy asymptotic method (GOHAM). Sheikholeslami et al. [45] used control volume based finite element method (CVFEM) to investigate the effect of magnetic on natural convection heat transfer of Cu–water nanofluid. Ellahi [47] used Homotopy analysis method to analytically study the effects of MHD and temperature dependent viscosity on the flow of non-Newtonian nanofluid in a pipe.

By a precise inspection of the results and discussions provided in the above researches, one can easily infer that the engineers of fluid mechanics society have taken a successful stride towards enhancing the thermal conductivity of the fluids [44,46,48–51]. To be more to the point, the results have illustrated that the thermal conductivity of nanofluid can be increased within the range of 10–50% via introduction of a small volume fraction of nanoparticles [12,13,16]. From computational point of view, it has been concluded that the mathematical complexity of Navier–Stokes equation hinder the engineers from developing exact techniques to solve the problem, and conduct a fully precise and valid analysis. Furthermore, it has been observed that the use of cumbersome numerical techniques imposes a remarkable burden on engineers, and thus a relatively accurate mesh based analysis is associated with lots of difficulties and expenses. In fact, the main reason of such difficulties emanates from the fact that most fluid mechanic problems inherit a complex nonlinear and transient behavior, just like many other practical phenomena [16,29].

Based on the general feed-back of the conducted researches, it can be easily infer that the proposition of computational approaches which can cope with the above difficulties, i.e. computational burden and nonlinearity of the system, is highly welcome. Apparently, the fascinating computational properties of intelligent modeling approaches can be a neat solution to the main computational difficulties associated with analyzing the behavior of