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On the effect of magnetic field on thermal performance of convective-radiative fin with temperature-dependent thermal conductivity

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Abstract

The removal of the excess heat by effective cooling technology is very vital for reliable operation, proper functioning and performance of thermal components, equipment and systems. In such phenomena, fins or extended surfaces play an essential and a very important role among various passive and active cooling options. In this paper, the effect of magnetic field on the thermal analysis of convective-radiative straight fin with temperature-dependent thermal conductivity is investigated using a new iterative method proposed by Daftardar-Gejiji and Jafari. The developed analytical solution is used not only to investigate the effects of magnetic parameter but also to establish the effects of convective and radiative parameters on the thermal performance of the fin under the influence of the magnetic field. From the results, it is established that increase in magnetic, convective and radiative parameters increase the rate of heat transfer from the fin and consequently improve the thermal performance of the fin. The results obtained are compared with the results established in the literature and good agreements are found. The analysis serves as a basis for comparison with any other method of analysis of the problem and also as a platform for improvement in the design of fin in heat transfer equipment under the influence of magnetic field.

Keywords: Thermal analysis; Convective-radiative fin; Daftardar Gejiji-Jafari method; Temperature-dependent thermal conductivity and magnetic field

1. Introduction

Passive effective cooling technology using extended surfaces has been a reliable method for enhancing heat transfer in thermal components, equipment, and systems. Indisputably, due to the wide areas of applications of extended surfaces, the study of fins for heat transfer enhancement in thermal components and devices has been a subject of interests over many years. Also, the investigation into the effects of the inherent nonlinearities in the developed thermal models (due to its temperature-dependent thermal properties) on the thermal performance of the passive devices has

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attracted a considerable amount of research works. In fact, in the past few decades, different solutions to the nonlinear equations have been developed using different techniques [1–23] such regular perturbation expansion [1,2], method of successive approximation [3], adomian decomposition method [4,5,8], homotopy perturbation method [6,7,9,12] homotopy analysis method [10,15,16], variational iteration method [11–14], differential transform method [17–23], least square method [24] and Galerkin method of weighted residual [25] to analyse the thermal behaviour and efficiency of fins.

Optimal homotopy analysis method (OHAM) is employed by Moitsheki et al. [26] in providing an analytical solution and numerical simulation for one-dimensional steady nonlinear heat conduction in a longitudinal radial fin with various profiles. Khania et al. [27] employed HAM to develop analytical solutions for the nonlinear fin problem with temperature-dependent thermal conductivity and heat transfer coefficient. Turkyilmazoglu [28] presented the closed-form temperature solutions for an exponential impermeable dry fin. Although, effects of various thermo-geometric parameters on the performance of fins have been studied in many literatures. Recently, Taklifi et al. [29] numerically studied the effect of MHD on a porous fin attached to a vertical isothermal surface while Rezazadeh et al. [30] determined temperature distribution in porous fin subjected to a uniform Magnetic and Hoshyar et al. [31] applied least square method to analyse porous fin in the presence of a uniform magnetic Field.

A new iterative method proposed by Daftardar–Jafari in 2006 has proven proved to be highly effective in solving linear and nonlinear problems of integer and fractional order [32–38]. This is because the DJM does not require many computations as carried out in Adomian decomposition method (ADM), homotopy analysis method (HAM), perturbation methods (PM), homotopy perturbation method (HPM), and variational iteration method (VIM). Also, the new iterative method as introduced by Daftardar-Gejiji and Jafari method [32–38] has fast gained ground as it appeared in many engineering and scientific research papers because of its comparative advantages over the other approximate analytical methods. The method converges to the exact solution if it exists through successive approximations. For concrete problems, a few numbers of approximations can be used for numerical purposes with high degree of accuracy. The presented of the method come with the associated error control procedures. Although, DJM and TAM are seen to be an improvement of Adomian decomposition method. Unlike the Adomian decomposition method, where the calculation of the tedious Adomian polynomials is needed to deal with nonlinear terms, DJM handles linear and nonlinear terms in a simple and straightforward manner without any additional requirements. DJM solves nonlinear differential equations of integral and fractional order without linearization, discretization, restrictive assumptions, perturbation and discretization or round-off error. It reduces the complexity of expansion of derivatives and the computational difficulties of the other traditional methods. Using DJM, a closed form series solution or approximate solution can be obtained as it provides excellent approximations to the solution of nonlinear equation with high accuracy. It is capable of greatly reducing the size of computational work while still accurately providing the series solution with fast convergence rate. It is a more convenient method for engineering calculations compared with other approximate analytical or numerical methods. It appears more appealing than the numerical solution as it helps to reduce the computation costs, simulations and task in the analysis of nonlinear problems. In DJM, there is no need for small perturbation parameter as required in traditional PM and the rigour of the determination of Adomian polynomials as carried out in ADM is avoided. DJM overcomes the restrictions of HPM to weakly nonlinear problems as established in the literature. Also, the lack of rigorous theories or proper guidance for choosing initial approximation, auxiliary linear operators, auxiliary functions, auxiliary parameters, and the requirements of conformity of the solution to the rule of coefficient ergodicity as done in HAM are not encounter in DJM. Furthermore, the requirement of developing differential transformations or recursive relations for the given differential equation as in DTM become unnecessary using DJM. The search Lagrange multiplier as carried in VIM is not needed in DJM. The challenges associated with proper construction of the approximating functions for arbitrary domains or geometry of interest as in Galerkin weighted residual method (GWRM), least square method (LSM) and collocation method (CM) are some of the difficulties that DJM overcomes.

To the best of the authors' knowledge, the study of the effects of magnetic field on the thermal performance of convective-radiative fin subjected to temperature-dependent DJM method has not be carried out. Therefore, in this study, we applied DJM to develop approximate analytical solutions for heat transfer and to study the effects of magnetic in

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