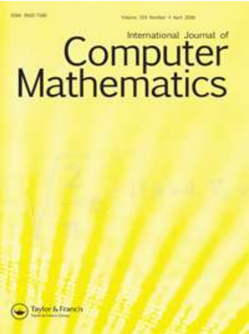

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RESEARCH ARTICLE

Analytical solution of a generalized fractional diffusion–advection equation

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ABSTRACT

In this study, a generalized nonlinear diffusion–advection equation of fractional order is defined. We incorporate a concentration-dependent diffusion coefficient and a nonlinear advection term. The defined nonlinear fractional differential equation is based on the Caputo fractional derivative. Using the Banach fixed-point theorem, we obtain the required conditions for the existence and uniqueness of the obtained results. The homotopy perturbation method (HPM) is used to derive an approximate analytical solution in series form. Some examples are provided to illustrate the efficiency and applicability of the proposed method. The results generalize and extend the previous work on fractional diffusion and Burgers-type equations.

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1. Introduction

Fractional calculus (FC) has gained significant importance in science and technology, attracting the attention of numerous mathematicians and researchers worldwide. Unlike classical calculus, FC is a branch of differentiation and integration into non-integer orders. This generalization has proven to be highly useful in recent years, as it provides effective tools for modelling and analysing complex phenomena in engineering, biology, geophysics, acoustics, biomedical sciences, signal and image processing, control theory, viscoelasticity, electricity, mechanics, and fluid dynamics. Extensive material is available for studying fractional calculus and its wide range of applications (see [4–32]). It has emerged as an influential tool for modelling phenomena involving memory, hereditary properties, and anomalous diffusion [17,22]. The Caputo fractional derivative, in particular, is widely used because of its compatibility with the initial physical conditions. Recent studies have shown that arbitrary-order models often provide a more suitable description of real-world processes than their integer-order counterparts [18].

From the literature analysis, we found that numerous established methods are available for solving classical calculus problems. However, when dealing with fractional differential equations, these techniques are comparatively limited. Furthermore, many nonlinear fractional differential equations lack exact analytical solutions. To address this, perturbation-based methods such as the Adomian Decomposition Method (ADM) [2–16,29] and, the Homotopy Perturbation Method (HPM) [13,14,29], have been developed. These approaches transform nonlinear problems into an infinite series of linear subproblems and approximate their solutions. Nevertheless, their applicability is limited because not all

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