Comparative Analysis of Analytical Solutions for Seepage Flow Derivatives in 4D Porous Media

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Abstract

Accurately modeling seepage flow dynamics in porous media is critical in environ mental science, hydrology, and engineering, especially in high-dimensional spaces with fractional derivatives. These flows present significant analytical challenges due to their inherent nonlinearity and complexity. Traditional solution methods often rely on simplifications that reduce accuracy. This study aims to provide a comparative evaluation of three advanced analytical techniques—the Homotopy Analysis Method (HAM), Adomian Decomposition Method (ADM), and Fractional Differential Transform Method (FDTM)—for solving a four-dimensional fractional partial differential equation governing seepage flow. By analyzing the convergence properties, computational efficiency, and solution accuracy of these methods, the study offers insights into their applicability to fractional seepage flow problems in porous media. The findings highlight the strengths and limitations of each approach, guiding researchers in selecting appropriate methods based on the problem's characteristics and the desired level of accuracy. This comparative analysis advances our understanding of nonlinear fractional systems and their solutions, with implications for environmental and engineering applications.

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Keywords

Fractional Derivatives, Nonlinear Equations, Homotopy Analysis Method (HAM), Adomian Decomposition Method (ADM), Fractional Differential Transform Method (FDTM).