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<td>Published Date</td>
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NUMERICAL SIMULATION OF VON KARMAN SWIRLING BIOCONVECTION IN NANOFLUID FLOW FROM A FIXED ROTATING DISK

Mr. Ali Kadir, S.R. Mishra, M. Shamshuddin and Dr. O. Anwar Bég

Introduction

Rotating disk bio-reactors are fundamental to numerous medical and chemical engineering processes including oxygen transfer, chromatography, purification and swit-assisted pumping [1]. The modern upsurge in bio-engineering devices has embraced new phenomena including bioconvection of micro-organisms (phototactic, magnetotactic, bio-tactic, gyrotactic etc.). The proven thermal performance superiority of nanofluids i.e. base fluids doped with engineered nano-particles, has also stimulated immense implementation in biomaterials design. Motivated by these emerging applications, in the current study, we study analytically and computationally the time-dependent 3-dimensional viscous gyrotactic bioconvection [2] in swirling nanofluid flow from a rotating disk configuration. This disk is also deformable i.e. able to extend (stretch) in the radial direction. Stefan blowing is included. The nanofluid is assumed to be dilute and the Buongiorno formulation [3] is adopted wherein Brownian motion and thermophoresis are the dominant nanoscale effects. Semi-numerical solutions are developed for the problem using the efficient Adomian decompositon method (ADM) [4]. Validation with earlier Runge-Kutta shooting computations in the literature is also conducted. Extensive computations are presented with the aid of MATLAB symbolic software for radial and circumferential velocity components, temperature, nano-particle concentration, micro-organism density number and gradients of these functions at the disk surface (radial skin friction, local circumferential skin friction, Local Nusselt number, Local Sherwood number, metal microorganism mass transfer rate). Extensive interpretation of the results is included. The work provides a useful benchmark for further computational fluid dynamics simulations of nano-bioconvection rotating disk reactors.

Methods and Numerical Solutions

Forced bioconvection in three-dimensional time-dependent viscous incompressible fluid flow over a rotating stretched disk is considered in a cylindrical polar coordinate system Velocity components in these coordinates are The nanofluid is assumed to be a dilute suspension with phototactic, magnetotactic, bio-tactic, gyrotactic microorganisms. The convective and no-slip boundary conditions are imposed at the disk surface. Stefan blowing is included in the (radial) velocity condition. The rotating disk flow model is illustrated in Fig. 1.

The nanosize microorganism populations species concentration close to the disk surface $c_{M} < \infty$ in order to simulate mass convective boundary conditions. Intrinsic to this is the presence of a different nano-particle concentration from the neighborhood to the disk boundary, concentration and ambient concentration which yields the required mass transfer coefficient $h_{m}$ with appropriate similarity variables, the convective boundary condition reduces to the following set of strongly coupled, nonlinear, multi-order, multi-degree ordinary differential equations for primary and secondary momentum, energy, nano-particle species and micro-organism density species conservation:

$$\frac{\partial y}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r f y) + \frac{1}{r} \frac{\partial}{\partial \theta} (f y) = \frac{1}{r} \frac{\partial}{\partial \theta} \left( \frac{1}{r} \frac{\partial y}{\partial \theta} \right)$$

The Adomian transformed boundary conditions:

$$f(0, \theta, t) = 0, f(\infty, \theta, t) = 0, f(0, 0, t) = 0, f(\infty, 0, t) = 0$$

ADM Results

Selected computations are shown below. For briefly we have restricted attention to single nano-particle species ($n = 1$), and Stefan blowing/suction ($\lambda > 0$). effects, we note that although a mass transfer blit number, $N_{D}$ appears in the boundary conditions it is prescribed value of $0.4$. This parameter is the solubility analogy to the thermal Blit number. Whereas thermal Blit number represents the ratio of convective to thermal mass transfer resistance, the mass transfer Blit number symbolizes the relative contribution of internal mass diffusion resistance to the external mass diffusion resistance. Since $N_{D} < 1$, in our simulations the external mass diffusion resistance dominates the internal mass diffusion resistance, and this relates to the nano-particle concentration field, not the micro-organism species.

Discussion

The ADM simulations generally show: how the radial stretching parameter decreases radial velocity and radial skin friction, reduces azimuthal velocity and skin friction, decreases local Nusselt number and metal micro-organism mass wall flux whereas it increases nano-particle local Sherwood number. (1)Disk deceleration accelerates the radial flow, damps the azimuthal decrease thermal temperatures and thermal boundary layer thickness, depletes the nano-particle concentration magnitudes (and associated nano-particle species boundary layer thickness) and furthermore decreases the micro-organism density number and gyrotactic micro-organism species boundary layer thickness. (2)Increasing Stefan blowing accelerates the radial flow and azimuthal (circumferential) flow, elevates temperatures of the nanofluid, boosts nano-particle concentration (volume fraction) and gyrotactic micro-organism density magnitudes whereas suction generates the reverse effects. (3)Increasing suction effect reduces radial skin friction and azimuthal skin friction, local Nusselt number, and metal micro-organism wall mass flux whereas it enhances the nano-particle species local Sherwood number. (4)ADM achieves very rapid convergence and highly accurate solutions and shows excellent promise in simulating swirling multi-physical nano-bioconvection. Physicists and engineers have good promise for bioheat transfer and mass transfer simulations.

References


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References