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Numerical Simulation of Von Karman Swirling Bioconvection Nanofluid Flow from a Deformable Rotating Disk

Authors : Ali Kadir, S. R. Mishra, M. Shamshuddin, O. Anwar Beg

Abstract : Motivation- Rotating disk bio-reactors are fundamental to numerous medical/biochemical engineering processes including oxygen transfer, chromatography, purification and swirl-assisted pumping. The modern upsurge in biologically-enhanced engineering devices has embraced new phenomena including bioconvection of micro-organisms (photo-tactic, oxy-tactic, gyrotactic etc). The proven thermal performance superiority of nanofluids i.e. base fluids doped with engineered nanoparticles has also stimulated immense implementation in biomedical designs. Motivated by these emerging applications, we present a numerical thermofluid dynamic simulation of the transport phenomena in bioconvection nanofluid rotating disk bioreactor flow. Methodology- We study analytically and computationally the time-dependent three-dimensional viscous gyrotactic bioconvection in swirling nanofluid flow from a rotating disk configuration. The disk is also deformable i.e. able to extend (stretch) in the radial direction. Stefan blowing is included. The Buongiorno dilute nanofluid model is adopted wherein Brownian motion and thermophoresis are the dominant nanoscale effects. The primitive conservation equations for mass, radial, tangential and axial momentum, heat (energy), nanoparticle concentration and micro-organism density function are formulated in a cylindrical polar coordinate system with appropriate wall and free stream boundary conditions. A mass convective condition is also incorporated at the disk surface. Forced convection is considered i.e. buoyancy forces are neglected. This highly nonlinear, strongly coupled system of unsteady partial differential equations is normalized with the classical Von Karman and other transformations to render the boundary value problem (BVP) into an ordinary differential system which is solved with the efficient Adomian decomposition method (ADM). 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, nanoparticle concentration, micro-organism density number and gradients of these functions at the disk surface (radial local skin friction, local circumferential skin friction, Local Nusselt number, Local Sherwood number, motile microorganism mass transfer rate). Main Findings- Increasing radial stretching parameter decreases radial velocity and radial skin friction, reduces azimuthal velocity and skin friction, decreases local Nusselt number and motile micro-organism mass wall flux whereas it increases nano-particle local Sherwood number. Disk deceleration accelerates the radial flow, damps the azimuthal flow, decreases 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. 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 number magnitudes whereas suction generates the reverse effects. Increasing suction effect reduces radial skin friction and azimuthal skin friction, local Nusselt number, and motile micro-organism wall mass flux whereas it enhances the nano-particle species local Sherwood number. Conclusions - Important transport characteristics are identified of relevance to real bioreactor nanotechnological systems not discussed in previous works. ADM is shown to achieve very rapid convergence and highly accurate solutions and shows excellent promise in simulating swirling multi-physical nano-bioconvection fluid dynamics problems. Furthermore, it provides an excellent complement to more general commercial computational fluid dynamics simulations.

Keywords : bio-nanofluids, rotating disk bioreactors, Von Karman swirling flow, numerical solutions
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