Simulating entropy generation in solar magnetohydrodynamic heat ducts with Eringen’s micropolar model and Bejan thermodynamic optimization

Kadir, A, Jangili, S, Beg, TA and Beg, OA

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Magnetohydrodynamic (MHD) solar power has recently been developed in the USA and is an exciting new area in renewable power. In this hybrid solar energy design, high-power (high-voltage) power is produced by engaging electricity from high-energy plasma and low-voltage (low-power) power from hot gas. The combined higher efficiency is achieved with MHD power converters. The significant heights are that MHD processes can be controlled in thermal systems that work at a much lower temperature. The working fluids in solar MHD designs may be non-Newtonian and are electroconductive and so can involve magnetic fields that strongly affect thermal convection effects as may also be present. To optimize thermal performance, Bejan’s entropy generation minimization (SGM) technique is a powerful approach. In the present paper we describe for the first time a novel analytical and computational model for entropy generation in magnetohydrodynamic (MHD) flows due to constant pressure gradient in a vertical-parallel plate channel as a simulation of an MHD solar power system. To more accurately calculate the thermal working fluid’s enthalpy, the elegant Eringen thermo-microstructural model is employed which features gaseous motions of micro-elements (suspended particles) - this is a new approach to real fluids like MHD power converters. The normalized conservation equations are solved with the powerful Lagrangian homotopy analysis method (LHAM) with physically viable boundary conditions at the channel’s duct walls. Numerical computations are conducted in MATLAB symbolic software. Results of selected parameters e.g. non-Newtonian couple stress parameter, Eringen micropolar parameter, Reynolds number, Bejan (thermal boundary) number, Newton number, and Brinkman number (viscosity) number are presented. The physical flow characteristics (velocity, temperature, Nusselt number) and on entropy generation number and Bejan number are calculated. The prescribed ranges of parameters are evaluated by using the assumptions of small differences between the duct walls’ working fluids and by employing non-Newtonian fluids. The computations show that increasing magnetic field effect is decreasing the enthalpy (energy) and the viscous (stress) behavior is observed for increasing couple stress parameter, Reynolds number, Bejan number and entropy generation number are observed to decrease the entropy generation production in solar MHD systems. The models designers in achieving thermally more efficient solar MHD duct performance.

**INTRODUCTION**

In recent years, engineers have verified that the entropy generation analysis via the Bejan’s entropy generation minimization (SGM) and the thermodynamic analysis of energy second law may become the first line of thermodynamics. It is established that thermal processes are inherently irreversible. Therefore, the main concern what describes the irreversibility of a system? Entropy generation in thermal systems is generally based by heat transfer which occurs due to differences in the flow temperatures. The general additional including fluid flow (velocity), buoyancy and magnetic field may also be accounted for. In this study the multiple porous zones of magnetic nanofluids and the other porous zones of magnetic nanofluids are pioneered by Bejan (1). The entropy generation analysis in ducts (e.g. parallel plate system) is a way to get modern thermodynamic engineering including the cooling of nuclear reactors, industrial heat exchanger optimization, porous media equipment performance enhancement, microelectronic devices, and microfluidic fluid theory, an advanced sub-branch of medicine, has mobilized significant theoretical frameworks (e.g. [9]). The main aim of the present work is to evaluate the entropy generation in a porous medium containing magnetic nanofluids. The numerical model is developed and tested against some existing reference cases. The enthalpy temperature boundary layer flow of magnetic nanofluids is naturally captured the suspension nature of the fluid mixture. Here we present numerical simulations for the energy second law of magnetohydrodynamic and magnetic field in entropy generation in incompressible electrically conducting thermo-microstructural fluid flow in a solar MHD duct. The numerical model is used (8). The governing momentum equations are non-dimensionalized and then solved subject to physically realistic boundary conditions. The results have been solved using the Homotopy Analysis Method (HAM). The influence of various thermophysical and thermofluidic parameters on linear velocity, microstructure, temperature and entropy fields distribution are displayed graphically and interpreted herein.

**MATHEMATICAL MODEL AND SOLUTION**

**MATHEMATICAL MODEL ctd.**

The equations are non-dimensionalized and the non-dimensional ordinary differential equation boundary value problem (ODE BVP) reduces to

\[
\begin{align*}
\frac{d^2\theta}{dy^2} + \frac{d^2\phi}{dy^2} + \frac{d^2\psi}{dy^2} &= 0, \\
\frac{d^2\theta}{dy^2} + \frac{d^2\phi}{dy^2} + \frac{d^2\psi}{dy^2} &= 0,
\end{align*}
\]

**HOMOTOPY NUMERICAL SOLUTION**

The coupled non-linear ODE BVP is solved with HAM. This method has generated exceptional results from biologists due to its approximate solutions in engineering and science. The other entropy generation problems HAM has been utilized successfully to obtain solutions for a diverse extent of multiphase dusty flows. The entropy generation number reduces the flow rate (a) and the flow rate (b) has the following forms of solution.

The homotopy deformation equations for velocity (a), micro-rotation (b) and temperature (c) as defined above:

\[
\begin{align*}
\frac{d}{dy} \left[ - \frac{1}{\rho} \frac{dP}{dy} + \rho u \frac{d^2u}{dy^2} \right] &= 0, \\
\frac{d}{dy} \left[ - \frac{1}{\rho} \frac{dP}{dy} + \rho \Omega \frac{d^2\Omega}{dy^2} \right] &= 0, \\
\frac{d}{dy} \left[ - \frac{1}{\rho} \frac{dP}{dy} + \rho \nu \frac{d^2\nu}{dy^2} + \frac{\mu \nu}{\rho} \frac{d^2\nu}{dy^2} \right] &= 0,
\end{align*}
\]

**BEIAN ENTROPY GENERATION ANALYSIS**

From the linear velocity, micro-rotation and temperature fields, the volumetric rates of entropy for an MHD micro-rotation fluid in the presence of magnetic field is given as

\[
S_{vol} = \frac{1}{\rho} \int \left[ - \frac{1}{2} \left( \frac{\partial u}{\partial y} \right)^2 + \frac{1}{2} \left( \frac{\partial \Omega}{\partial y} \right)^2 + \frac{1}{2} \frac{\partial \nu}{\partial y} \right] \, dy + \frac{1}{\rho} \int \left[ \frac{1}{2} \left( \frac{\partial u}{\partial y} \right)^2 + \frac{1}{2} \left( \frac{\partial \Omega}{\partial y} \right)^2 + \frac{1}{2} \frac{\partial \nu}{\partial y} \right] \, dy
\]

**CONCLUSIONS**

Selected HAM computations are shown in Figs 5-6b. The main observations of the present study can be summarized as follows:

1. Increasing couple stress effect in the working fluid decreases the velocity.
2. An elevation in micropolar (vorticity) parameter decreases the velocity in comparison with the Newtonian fluid case. Further, it is noticed that micropolar parameter can be used to control the flow motion.
3. The entropy generation production is maximum near to the solar plate ducts as compared to that of the duct channel cross-section. This demonstrates that the thickness of the duct channel is dominant near the channel plates and these enhance entropy generation. Conversely, Bejan numbers have minimum values near the plates and maximum value near the channel center.
4. Bejan number is a maximum at the centre point of the channel. This reveals that the amount of available energy for work is more and univocality in less.
5. A strong increase in entropy generation distribution (5e) is noted with an increase in couple stress parameter (a), Bejan number (b), Bejan number (c) and parameter group (Brric).
6. The micropolar parameter (a) and magnetic parameter (b) have decreasing effect on entropy generation production.

The present study has demonstrated the powerful ability of HAM in simulating entropy generation problems in non-Newtonian magnetohydrodynamics solar duct systems. However, it has neglected thermal radiation heat losses effect (b), 10 which are present under consideration with algae flux and differential models (Kholeifat, Pt, Chanthachar).