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# Simulation of double diffusive MHD (magnetohydrodynamic) natural convection and entropy generation in an open cavity filled with power-law fluids in the presence of Soret and Dufour effects (part II: entropy generation)

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ABSTRACT

In this paper, entropy generation of associated with double diffusive natural convection of non-Newtonian power-law fluids in an open cavity in the presence of a horizontal magnetic field, studying Soret and Dufour parameters has been analyzed by FDLBM (Finite Difference Lattice Boltzmann method). This study has been performed for the certain pertinent parameters of Rayleigh number (Ra = $10^4$ and $10^5$), Hartmann number (Ha = 0, 15, and 30), power-law index (n = 0.6, 1, and 1.4), Lewis number (Le = 2.5 and 5), Dufour parameter ($D_f$ = 0, 1, and 5), Soret parameter ($S_r$ = 0, 1, and 5) and the buoyancy ratio (N = −1and 1). Results indicate that the augmentation of the thermal Rayleigh number enhances different entropy generations and declines the average Bejan number. The increase in the Hartmann number provokes various irreversibilities to enhance and the average Bejan number decreases significantly. The enhancement of Lewis number and buoyancy ratio affect various entropy generations and the average Bejan number. The rise of Soret and Dufour parameters enhances the entropy generations due to heat transfer and fluid friction. The change of power-law index alters various entropy generations, but the alteration does not follow a specific manner in different studied parameters.
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## 1. Introduction

Flow in an enclosure driven by buoyancy force is a fundamental problem in fluid mechanics. This type of flow can be used as validation in academic researches and various applications of engineering [1–3]. Natural convection in open cavities have received a considerable attention [4–6] due to their applications in various industries of high-performance insulation for buildings, injection molding, chemical catalytic reactors, packed sphere beds, grain storage, float glass production, air-conditioning in rooms, cooling of electronic devices, and such geophysical problems. The flow of an electrically conducting fluid in a magnetic field is influenced by MHD (magnetohydrodynamic) () forces resulting from the interaction of induced electric currents with the applied magnetic field. An externally imposed magnetic field is a widely used tool for the process of manufacturing metals. The molten flows in this process behave usually like non-Newtonian power-law fluid; therefore, it is not possible practically to be studied as a Newtonian fluid. For example, a magnetic field is applied on the melt during solidification process in injection molding in Magnesium Injection Molding. Moreover, as we know the dominant heat transfer process in injection molding is convection while the melt behaves like power-law non-Newtonian fluid [7]. The effect of magnetic field on the convection process in cavities on different fluids and boundary conditions has been studied by various numerical methods widely [8,9]. In addition, several investigations on natural convection for non-Newtonian power-law fluids in a cavity were conducted by researchers with different models and numerical methods [10–12]. However, some limited studies of the MHD natural convection of power-law fluids in an enclosure have been conducted in the absence of the mass transfer [13–15].

Moreover, the mass transfer plays a crucial role in the mentioned applications and therefore it is significant that the double diffusive natural convection on the problem to be

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**Nomenclature**

| | |
|---|---|
| *Be* | Bejan number |
| *C* | Concentration |
| *c* | Lattice speed |
| $c_p$ | Specific heat at constant pressure |
| *D* | Mass diffusivity |
| $D_f$ | Dufour parameter |
| F | External forces |
| *f* | Density distribution functions |
| $f^{eq}$ | Equilibrium density distribution functions |
| *g* | Internal energy distribution functions |
| $g^{eq}$ | Equilibrium internal energy distribution functions |
| $g_y$ | Gravity |
| *Ha* | Hartmann number |
| *k* | Thermal conductivity |
| $k_{TC}$ | The thermodiffusion coefficient |
| $k_{CT}$ | The diffusionthermo coefficient |
| *L* | The length of the cavity |
| *Le* | Lewis number |
| *n* | Power-law index |
| *Nu* | Nusselt number |
| *N* | Buoyancy ratio |
| *P* | Pressure |
| *Pr* | Prandtl number |
| *R* | Gas constant |
| *Ra* | Rayleigh number |
| *S* | Entropy |
| *Sh* | Sherwood number |
| $S_r$ | Soret parameter |
| *T* | Temperature |
| *u* | Velocity in x direction |
| *v* | Velocity in y direction |
| *t* | Time |
| *x,y* | Cartesian coordinates |

*Greek letters*

| | |
|---|---|
| $\beta$ | Thermal expansion coefficient |
| $\phi$ | Relaxation time |
| $\tau$ | Shear stress |
| $\zeta$ | Discrete particle speeds |
| $\Delta x$ | Lattice spacing |
| $\Delta t$ | Time increment |
| $\alpha$ | Thermal diffusivity |
| $\rho$ | Density |
| $\mu$ | Dynamic viscosity |
| $\psi$ | Stream function value |

*Subscripts*

| | |
|---|---|
| *avg* | Average |
| *C* | Cold |
| *H* | Hot |
| *x,y* | Cartesian coordinates |
| $\alpha$ | The number of the node |
| *F* | Fluid friction |
| *S* | Summation |
| *T* | Thermal |
| *tot* | Total |
| *D* | Solutal |

investigated. On the other hand, in the double diffusive natural convection of different enclosures, the important parameters of Soret and Dufour have been usually neglected while it has demonstrated [16] they affect heat and mass transfer considerably. One of the main applications of this study is observable in the magnetic refrigerators using microchannel regenerators [17] where the water-glycol can be applied as the basic fluid [18]. In this application, a relative and changing magnetic field is applied into the microchannel regenerators and creates an external magnetic field. The external magnetic field can affect the heat and mass transfer in the microchannel. In addition, the viscosity of the water-glycol demonstrates a power-law manner [19] in a wide range of temperatures.

The optimal design of the cited industries is obtained with precision calculation of entropy generation since it clarifies energy losses in a system evidently. Entropy generation on natural convection in the presence and absence of mass transfer for different fluid flows has been scrutinized widely. Ilis et al. [20] investigated entropy generation in rectangular cavities with different aspect ratios numerically. It was demonstrated that heat transfer and fluid friction irreversibility in a cavity vary considerably with the studied aspect ratios. In addition, the total entropy generation in a cavity increases with Rayleigh number, however, the rate of increase depends on the aspect ratio. Saleem et al. [21] conducted a numerical study of natural convection and entropy generation in an open cavity filled with a Newtonian fluid. It was observed that due to low thermal conductivity and heat transfer, the active spot of entropy generation rests at the center of the opening of buoyancy cell when the values of Prandtl number and Grashof number are not too high, but the heat transfer irreversibility along the sold walls play dominant role for relatively large values of Prandtl number and Grashof number. Kaluri and Basak [22] simulated entropy generation during natural convection in porous square cavities heated with differential and distributed heating methodologies using finite element method. Just recently, Kefayati [23] scrutinized entropy generation of double diffusive natural convection with Soret and Dufour effects in a square cavity filled with non-Newtonian power-law fluid. It was indicated that the augmentation of the power-law index causes different types of entropy generation to drop. As the literature review demonstrates, the double diffusive natural convection of power-law fluid in the presence of a magnetic field and the entropy generation during this process has not studied thus far.

The main aim of this study is to simulate and analyze the entropy generation of double diffusive natural convection of non-Newtonian power-law flow in an open cavity in the presence of a magnetic field with studying Soret and Dufour parameters. Mesoscopic methods have been utilized in different problems successfully [24–29]. FDLBM (Finite Difference Lattice Boltzmann method) as an innovative mesoscopic numerical method is applied to solve the complicated problem since the method is utilized for simulation of double diffusive natural convection and entropy generations in an inclined porous cavity with Soret and Dufour effects recently [30,31]. The results of FDLBM are validated with previous numerical investigations and the effects of the main parameters (Thermal Rayleigh number, power-law index, Lewis number, Buoyancy ratio number, Soret parameter, Dufour parameter, and Hartmann number) on the entropy generations of fluid friction, magnetic field, heat and mass transfer are studied.

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