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ORIGINAL ARTICLE

Study of heat and mass transfer with Joule heating on magnetohydrodynamic (MHD) peristaltic blood flow under the influence of Hall effect

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Abstract In this article, heat and mass transfer with Joule heating on magnetohydrodynamic (MHD) peristaltic blood under the influence of Hall effect is examined. Mathematical modelling is based on momentum, energy and concentration which are taken into account using ohms law. The governing partial differential equations are further simplified by neglecting the inertial forces and long wavelength approximations. Exact solutions have been presented for velocity, temperature and concentration profile. The influence of all the physical pertinent parameters is taken into account with the help graphs. It is found that Hartmann number and Hall parameter shows opposite behaviour on velocity, temperature and concentration profile. It is worth mentioning that pressure rise also depicts opposite behaviour for Hartmann number and Hall parameter. The present analysis is also presented for Newtonian fluid ($\alpha \rightarrow 0$) as a special case for our study. It is observed that Hall Effect and magnetic field shows opposite behaviour on velocity and temperature profile. Temperature profile increases due to the increment in Prandtl number and Eckert number. Numerical comparison is also presented between the existing published results by taking $\alpha = 0, M = 0$ as a special case of our study.

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Nomenclature

$\tilde{u}, \tilde{v}$	velocity components (unit: m/s)
$\tilde{x}, \tilde{y}$	Cartesian coordinate (unit: m)
$\tilde{p}$	pressure in fixed frame (unit: N/m^2)
$\tilde{a}$	wave amplitude (unit: m)
$b(\tilde{x})$	width of the channel
$\tilde{c}$	wave velocity (unit: m/s)
Pr	Prandtl number
Ec	Eckert number
Re	Reynolds number
$\tilde{t}$	time (unit: s)
$\overline{K}(\ll 1)$	constant
$\boldsymbol{E}$	electric field (unit: V/m)
B_0	magnetic field (unit: T)
Sc	Schmidt number
Sr	Soret number
$\tilde{\boldsymbol{V}}$	velocity field (unit: m/s)
Q	volume flow rate (unit: m^3/s)
T, C	temperature (unit: K) and concentration
$\boldsymbol{J}$	current density (unit: A)
D	mass diffusivity (unit: m^2/s)
T_m	mean temperature
K_T	thermal diffusion ratio
M	Hartman number
$\boldsymbol{S}$	stress tensor
m	Hall parameter

Greek symbols

κ	fluid thermal conductivity (unit: W/(m $\cdot$ K))
μ	viscosity of the fluid (unit: N $\cdot$ s/m^2)
Φ	dimensionless concentration
σ	electrical conductivity (unit: S/m)
δ	wave number (unit: m^{-1})
θ	dimensionless temperature
ζ_0	effective heat capacity (unit: J/K)
ν	kinematic viscosity (unit: m^2/s)
α	Ree-Ering fluid parameter
ρ	fluid density (unit: kg/m^3)
λ	wavelength (unit: m)
ϕ	amplitude ratio

1. Introduction

In the past few years, the peristaltic flow has received remarkable attention by various authors [1–5] due to its importance in engineering, physiological and medical science. The peristaltic mechanism can be observed in a living body such as urine transport from a kidney to the bladder, vasomotion of small blood vessels, swallowing food through an oesophagus and male reproductive tract (duct afferents) etc. Various devices have been invented that follow the principle of peristalsis such as finger pumps, peristaltic pumps, roller pumps and the heart-lung machine etc. Especially during the past few years, non-Newtonian fluid also received a major attention due to its application in engineering and biomedical sciences [6–8]. Moreover, Peristaltic flow under the influence of magnetic field is very much important in magnetic drug targeting for cancer diseases, hyperthermia, magnetic resonance imaging (MRI) and Magneto-therapy. Ellahi et al. [9] studied the effects of Magnetohydrodynamics on peristaltic flow of non-Newtonian Jeffrey fluid in a porous rectangular duct. He found that due to the effect of magnetic field, the velocity of the fluid decreases which is very much helpful to control the flow. Hayat et al. [10] investigated the simultaneous effects of Hall current with homogenous and heterogeneous reactions on peristaltic flow. Again, Hayat et al. [11] analysed the influence of magnetic field on peristaltic motion of Williamson fluid in an inclined channel having convective boundary conditions. Mekheimer and Al-Arabi [12] investigated the nonlinear peristaltic motion of magnetohydrodynamic (MHD) flow through a porous medium.

Peristaltic flow with heat and mass transfer has also various applications in geophysical engineering and geothermal. The importance of heat exchange with peristaltic mechanism cannot be neglected due to its applications in solar ponds, lubrication technology, diffusion of different nutrients from blood, drying technology, a dynamic of lakes, haemodialysis and nuclear reactors. Of course, the mass transfer also plays an important role in reverse osmosis, separation process, diffusion of chemical impurities, distillation and combustion process. Nadeem et al. [13] studied the influence of heat and mass transfer on peristaltic motion of Johnson Segalman fluid in a vertical asymmetric channel under the influence of induced magnetic field. Hayat et al. [14] investigated the peristaltic flow of third-grade fluid with heat and mass transfer under the influence of wall properties. Ellahi et al. [15] examined the heat and mass transfer on peristaltic flow of viscous fluid in a non-uniform rectangular duct. Some pertinent studies on the said topic can be found in the Refs. [16–21].

Peristaltic blood flow (or hemodynamic) problems have received a considerable attention due to its major importance in physiopathology. For a long time, blood is treated as a vital fluid. Blood circulation performs various types of function in a human body such as transport of nutrients, transport of oxygen, removal of metabolic products and removal of carbon dioxide. Blood circulation is divided into three types such as capillary circulation, systemic circulation, and microcirculation. Blood consists of various types of formed elements and plasma which include red blood cells (RBC), white blood cells (WBC) and platelets. In normal circumstances, blood depicts laminar characteristics that is why the velocity of the blood is higher in the middle of the vessel/channel as compared to the walls. The velocity of the blood can be measured in different ways like laser Doppler anemometry or video-capillary micro-scoping with a frame to frame analysis. Mekheimer [22] again considered the effects of magnetic field on peristaltic blood flow of

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