International Journal of Heat and Mass Transfer 106 (2017) 127–134

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Mixed convection flow of magnetohydrodynamic micropolar fluid due to a porous heated/cooled deformable plate: Exact solutions

M. Turkyilmazoglu

Department of Mathematics, Hacettepe University, 06532 Beytepe, Ankara, Turkey

ARTICLE INFO

Article history:
Received 27 August 2016
Received in revised form 12 October 2016
Accepted 15 October 2016

Keywords:
Micropolar fluids
Mixed convection
Stretching surface
Magnetohydrodynamics
Heat generation/absorption
Heat transfer
Mass transfer

ABSTRACT

The present work deals with the magnetohydrodynamic mixed convection flow and heat as the consequence of a micropolar fluid past a heated or cooled stretching permeable surface by taking into account heat generation and absorption effects. The objective is to mathematically resolve the flow and heat fields and their domain of existence. A magneto-convection parameter is defined first controlling the effects of convection buoyancy and magnetic field. Explicit solutions are then derived for the flow, temperature and concentration fields. The existence and uniqueness of the solutions, the heating and cooling influences of the wall, the magnetic effects, the skin friction as well as the rate of heat transfer are better understood by means of the presented formulae.

1. Introduction

Since the pioneering microfluid model of Eringen [1] certain real fluid flows have been explored from the framework of micromotions of the fluid elements. A subclass of microfluids, called micropolar fluids was also developed by Eringen [2]. A generalized theory associated with the thermomicropolar fluid was further given by Eringen [3].

Moreover, some real applications concerning micropolar flows may be inferred from [4,5]. A rich survey of the past and recent works done concerning the micropolar fluids and, their technological and industrial applications were recently presented in [6]. One can also refer to the studies by Ariman et al. [7], Na and Pop [8], Nazar et al. [9], Ishak [10], Mahmoud and Waheed [11], Turkyilmazoglu [12–14] and Ahmad [15–18] amongst many others. Particular recent research on the micropolar liquid was concerned with the nonlinear stretching with convective condition [19], radiative and Joule heating with partial slip [20], peristaltic motion of a micropolar fluid in a tube [21] or in a channel [22]. In addition to the aforementioned numerical researches on the micropolar fluids over different media, interesting analytical results were also presented lately in Turkyilmazoglu [23,24].

Even though a variety of numerical methods were employed to explore the micropolar fluid flow and heat transfer induced by a permeable sheet stretching in the literature, not an analytic study has been implemented yet. The motivation here is therefore to propose an analytical mean to derive exact solutions. From these explicit expressions, the magnetic field and heat generation absorption impacts defined via a fresh parameter so called as the magneto-convection parameter [25] and its influences on the flow parameters can be studied. Further physical features of the system can also be analyzed from the presented formulae.

2. Flow equations

The target is to examine the vertically imposed magnetic field on a porous deformable surface and the affected energy and momentum equations. The buoyancy effects and also heat generation/absorption are taken into consideration. The physical problem has been successfully formulated and treated in the literature. For the sake of being concise, we only give the resultant governing equations of the flow motion and heat transfer, see for example, [5,8–10].

$$\begin{aligned} (1+K)f''' + ff'' - f'^2 + Kh' - Mf' + \Lambda\theta &= 0, \\ (1+K/2)h'' + fh' - f'h - K(2h+f'') &= 0, \\ \theta'' + Pr(f\theta' - f'\theta) + \gamma\theta &= 0, \end{aligned} \tag{2.1}$$

subject to the boundary conditions

E-mail address: turkyilm@hotmail.com

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.10.056
0017-9310/

Table 1
Effects of Λ on the skin friction $f''(0)$.

Λ	Yih [28]	Hayat [29]	Present
0.0	−1.0000	−1.000000	1.00000000
0.5	−1.2247	−1.224747	1.22474487
1.0	−1.4142	−1.414217	1.41421356
1.5	−1.5811	−1.581147	1.58113883
2.0	−1.7321	−1.732057	1.73205081

$$
\begin{aligned}
&f(\eta)=s,\ f'(\eta)=1,\ h(\eta)=-mf''(\eta),\ \theta(\eta)=1 \quad \text{at} \quad \eta=0,\\
&f'(\eta)\to 0,\ h(\eta)\to 0,\ \theta\to 0 \quad \text{as} \quad \eta\to\infty,
\end{aligned}
\tag{2.2}
$$

where η is a dimensionless boundary layer coordinate, $f'(\eta)$ is to shown the similarity velocity component, while similarity microrotation or angular velocity is denoted by $h(\eta)$, M denotes magnetic interaction parameter, Λ stands for buoyancy (convection) parameter, s is the wall transpiration such that $s<0$ means suction and $s>0$ injection, K is the material parameter, m represents a measurement for the concentration of microelements taken in the interval $0\leqslant m\leqslant 1$, respectively. Moreover, θ is the dimensionless fluid temperature, Pr is the usual Prandtl number. Furthermore, the heat generation or absorption is due to positive or negative γ. parameter. We are primely interested in the local scaled wall shear combined with couple stress

$$-(1+K(1-m))f''(0)$$

and the scaled local Nusselt number

$$-\theta'(0),$$

which are to be evaluated from (2.1) and (2.2).

3. Exact analytic solutions

In place of the available numerical solutions in the open literature, this section offers exact analytic solutions. Considering the work by Crane [26] as well as by Ahmad [15,16], the exponential kind solutions may be sought

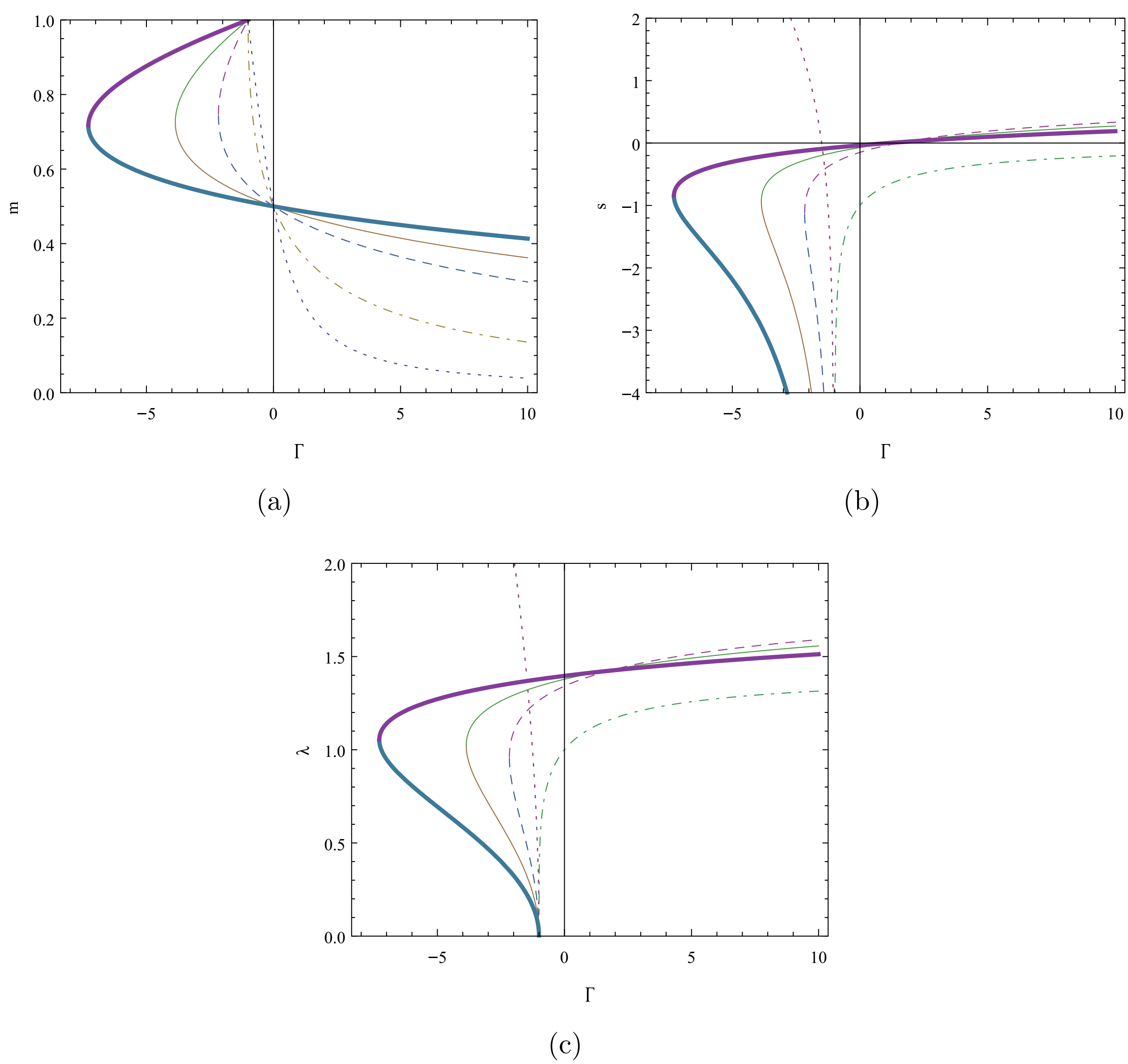

Fig. 1. The solution domains for the triple (m,s,λ); curves, respectively, dotted ($K=1/5$), dot-dashed ($K=1$), dashed ($K=5$), thin ($K=10$) and thick ($K=20$), as a function of the magneto-convection parameter Γ at $\Pr=1$ and $\gamma=-1$. (a) m, (b) s and (c) λ.