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COMPUTATIONAL INVESTIGATION OF COUETTE FLOW OF HEAT GENERATING/ABSORBING FLUID IN A CHANNEL DUE TO NONLINEAR THERMAL RADIATION, TEMPERATURE DEPENDENT VISCOSITY AND TEMPERATURE DEPENDENT THERMAL CONDUCTION

***Yusuf, A. B. and Jushua, A.**

Department of Mathematics, Federal University Dutsin-Ma, Katsina State

*Corresponding authors' email: ayusuf@fudutsinma.edu.ng

ABSTRACT

A computational investigation of Couette flow of heat generating/absorbing fluid in a channel due to nonlinear thermal radiation, temperature dependent viscosity and temperature dependent thermal conduction is considered in this paper. The channel in which the fluid flow is assumed to be formed by two parallel infinite vertical plates in which one of the plates is assumed to move with a constant velocity in the direction of fluid flow while the other is stationary. A uniform radiative heat flux applied through the moving porous channel and this penetrate into the fluid. The fluid is considered to be a heat generating/absorbing one and that both its viscosity and thermal conduction depend on temperature variation. Under these assumptions, the mathematical equations representing this flow are given and are solved using a semi-analytical method of solution and computer simulation. To witness the insight of the flow phenomenon; graphs of velocity and temperature fields are displayed for the pertinent parameters of interest with discussion.

Keywords: Couette flow, Nonlinear thermal radiation, Temperature dependent viscosity, Temperature dependent thermal conduction, Heat generating/absorbing fluid

INTRODUCTION

Flow of fluid which occurs due to the movement of bounding surface surrounding the fluid is termed as Couette flow. Yosutomi (1984) reported that this type flow is of fundamental application in hydrodynamics lubrication in fluid machinery which involve moving parts and that it is vital method used for the measurement of viscosity and also used as a means of estimating drag force in many wall driven applications.Many authors investigated flow of fluids when its viscosity is dependent on temperature variation. This idea of principal interest in many scientific and technological innovations like in the extraction of metals from ores, crude oil extraction in petroleum industries, automobiles industries, coating of metals and so on. It was reported in the study of John and Narayanan (1997) that the most sensitive property of fluid to temperature change is the viscosity. In the Gray (1982), it was reported that the flow characteristics of fluid changes significantly on consideration of temperature depended viscosity.Kafousius and Rees (1998) established that when the viscosity of any fluid is sensitive to temperature variation, the effect of temperature-dependentviscosity has to be taken into account or elsesignificant errors may results in the heat transfer characteristics. In order to see related literatures, it can be referred ToIyer et al. (1997), Ingham and Pop (1998), Urbano and Nasuti (2013), Daniel (2017) and Prenay*et al.* (2019).

Fluid flow with thermal conductivity that depend on temperature changes has been discussed by investigators owing to its various bids in engineering as in the extrusion of plastic sheets, polymer processing, spinning of fibers, cooling of elastic sheets etc. The quality of final products in manufacturing industries relies solely on the rate of heat transfer and as such cooling procedure has to be controlled for effective performance. In many heat sink/ source applications; materials of high thermal conductivity are widely used as heat conductors while those of low conductivity are used as insulators. For instance, liquid metals withPrandtl number in the range of 0.01 – 0.1 are commonly used as coolants because of their high thermal conductivity. In Van den Berg et al. (2015) it was conveyed that variable thermal conductivity can delay secular cooling of mantle with constantviscosity model and that of Sharma and Aisha (2014) disclosed that thermal conduction increases with decrease in Prandl number. Related studies can be observed in Dubuffet (1999), Hofmeister (1999), Starlin*et al.* (2000), van den Berg *et al.* (2001) and Rihab et al. (2017).

Thermal radiation is of essential use in system maintenance such as in cooling of human body for temperature regulation, heat source or sink application as in electric cookers, drying of agricultural products, warming of houses, bakerymedical treatment as in curing of tumor, sterilization of surgery equipment used in surgery operations etc. It is to this regard that Rosseland (1931) gave an expression for thermal radiation and this was later simplified by Sparrow and Cess(1962). The simplified version is being in used to study heattransfer with thermal radiation by scholars, this can be observed in Elbasbeshy and Bazid (2000), Schlicting and Mahmud (2002), Ibanez *et al.*(2003), Makinde (2005), Makinde*et al.* (20077), Makinde and Ogulu(2008) and Ibrahim and Makinde (2011). In few of the above cited studies, the authors discussed the effect of thermal radiation using linear form of thermal radiation and this was however faulted by Magyari and Pantokratoras(2011) that the approach does not mirrorsthe real process in heat transfer characteristics. They therefore offered alternative procedure using non-linear thermal radiation. In apprehension of this novelty, correlated studies can be witnessed in Yabo*et al.*(2016), Jha*et al.*(2017) and Ajibade and Bichi(2918).

In the flow of heat transfer (thermodynamics), the process of heat transfer is greatly persuaded by the thermal absorption/generation of the material medium. Heat transfer process occurs at a lower rate across materials of low thermal conductivity than across materials of high thermal conductivity. Objects which absorb high heat are generally used in heat sink applications while those of low conductivity are used as thermal insulators. In view of the importance of thermal conductivity in industrial processing; the final product depends on the rate of heat transfer and therefore the cooling procedure has to be managed effectively. It is in line of this that Foraboschiand Federico (1964) presented the volumetric rate of heat generation and explained that it is an approximation of the state of some exothermic process with the initial temperature of the fluid. Heat generation/absorption plays significant role in various physical phenomena such as convection in earth's mantle (McKenzie *et al.*, 1974), application in the field of nuclear energy (Crepeau and Clarksean, 1997), post-accident heat removal (Baker *et al.* 1976), fire and combustion modeling (Delichatsios, 1988), and the development of metal waste from spent nuclear fuel (Westphal 1994). Jha (2001) disclosed that the study of flow of heat generating/absorbing fluid has been of great interest because as the temperature differences are amplified appreciably, the volumetric heat generation/absorption term may exert strong influence on the heat transfer and transitively on the fluid flow. Different attributes to internal heat generation were accorded to many investigations; for instance, it was assumed to be constant in the study conducted by Inman (1962) while that of Ostrach (1954) asserted that heat generation is a result of frictional heating and expansion effects of the working fluid.

It is in view of this literature that the present article investigates Couette flow of heat generating/absorbing fluid in a channel due to nonlinear thermal radiation, temperature dependent viscosity and temperature dependent thermal conduction using Adomian decomposition method (ADM). The selection of this method is because of its abundant importance as given in Adomian (1994).

MATERIALS AND METHODS

The Problem

Consider one-dimensional steady laminar flow of an incompressible heat generating/absorbing viscous fluid in a vertical channel formed by two infinite parallel plates kept h distance apart in which one of the plates is assumed to be stationary and the other is moving with a velocityU_0. A radiative heat flux of intensity q_r is applied through the moving plate and is transferred into the fluid. It is considered that all the thermos-physical properties of the fluid are constant except that the viscosity and thermal conduction which depend with temperature variation. Under these situations and that on the assumption of Boussinessque:s approximation, the governing equations for the flow and the boundary conditions can be written as:

$$\frac{1}{\rho}\frac{d}{dy'}\left(\mu\frac{du'}{dy'}\right)+g\beta(T'-T_0)=0 \quad (1)$$

$$\frac{1}{\rho C_\rho}\frac{d}{dy'}\left(k\frac{dT'}{dy'}\right)-\frac{1}{\rho C_\rho}\frac{dq_r}{dy'}-\frac{q}{\rho C_\rho}-\mu\left(\frac{du'}{dy'}\right)^2=0 \quad (2)$$

Equation (1) is the momentum equation with the first term represents the fluid flow due to changing viscosity with the second term representing the flow due to buoyancy force. In the energy equation (2), the first term is the energy on the flow due to varying thermal conductivity, the second term is the term due to thermal radiation and third term a rising due to viscous dissipation with the last term as the heat generating and absorbing parameters.

The radiative heat flux as reported by Sparrow and Cess (1978) has the form.

$$q_r=\frac{-4\delta\partial T}{3\delta\partial y'} \quad (3)$$

and the fluid viscosity and thermal conduction as given by Carey and Mollendorf (1978) respectively of the form:

$$\mu=\mu_0\left(1-b\left(\frac{T'-T_0}{T_w-T_0}\right)\right) \quad (4)$$

$$k=k_0\left(1-a\left(\frac{T'-T_0}{T_w-T_0}\right)\right),\ a,b\,\epsilon\,(0,1) \quad (5)$$

while the heat generating/absorbing term as:

$q=Q(T'_w-T'_0)$(Forabaschi and Federico (1964)) (6)

andthe boundary conditions are:

$$u'=0,\quad T'=T_w\quad at\quad y'=0$$
$$u'=U_0,\ T'=T_0\quad at\,y'=h \quad (7)$$

and the dimensionless quantities:

$$u=\frac{u'}{u_0},\ y=\frac{y\prime}{h},\ \theta=\frac{T'-T_0}{T_w-T_0}, \quad (8)$$

In view of equations (3, 4, 5,6 and 7), equations (1 and 6) are transformed to the following dimensionless form:

$$u''=\lambda(1+\lambda\theta)u'\theta'-Gr\theta(1+2\lambda\theta) \quad (9)$$

$$\theta''=\varepsilon\theta'^2(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]-4R(\theta+\phi)^2\theta'^2(1+\varepsilon\theta)[1-4R(1+\varepsilon\theta)(\theta+\phi)^3]+H\theta(y)(1+\varepsilon\theta)[1-4R(1+\varepsilon\theta)(\theta+\phi)^3]+Br(1-\lambda\theta(y))u'^2(y)(1+\varepsilon\theta)[1-4R(1+\varepsilon\theta)(\theta+\phi)^3] \quad (10)$$

where $=\frac{g\beta h^2\theta\Delta T}{\upsilon_0}$, $R=\frac{4\sigma\Delta T^3}{\delta K_0}$, $E_C=\frac{u_0{}^2}{\rho C_p\Delta T}$, $H=\frac{q_0h_2}{K_0}$,

$$P_r=\frac{\mu C_p}{K_0},\ Br=EcPr \quad (11)$$

Note that the single prime denotes first derivative with respect to y with the double primes represent second derivative with respect to y. Furthermore, the meaning of the letters presented through can be referred to the table of nomenclature.

Adomian Decomposition Solution (ADM) of the Problem

ADM which is a semi-analytical method of solution is deployed to solve the differential equation (9 - 10). This choice is due to the complexity of the equations which cannot be solve easily using analytical means. In view of this, we write equation (3.7) and (3.9) in operator forms as:

$$LU=\lambda(1-\lambda\theta)u'\theta'-Gr\theta(1+2\lambda\theta) \quad (12)$$

$$L\theta=\varepsilon\theta'^2(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]-4R(\theta+\phi)^2\theta'^2(1-\varepsilon\theta)(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]+H\theta(y)(1+\varepsilon\theta)(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]+Br(1-\lambda\theta(y))u'(y)(1+\varepsilon\theta) \quad (13)$$

Where L is a second order differential operator with

$$L=\frac{d^2(\cdot)}{dy^2}\text{and}L^{-1}(\cdot)=\int_0^y\int_0^y(\cdot)dydy \quad (14)$$

Now taking L^{-1} to both side of equation (13 - 14) together with the use of equation (7) we get:

$$U(y)=yA+L^{-1}\lambda(1-\lambda\theta)u'\theta'-Gr\theta(1+2\lambda\theta) \quad (15)$$

$$\theta(y)=1+yB+L^{-1}\varepsilon\theta'^2(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]-4L^{-1}R(\theta+\phi)^2\theta'^2(1-\varepsilon\theta)[(1+\varepsilon\theta)1-4R(1-\varepsilon\theta)(\theta+\phi)^3]+L^{-1}H\theta(y)(1+\varepsilon\theta)[(1+\varepsilon\theta)1-4R(1-\varepsilon\theta)(\theta+\phi)^3]+L^{-1}Br(1-\lambda\theta(y))u'(y)(1+\varepsilon\theta) \quad (16)$$

Where $A=f'(0)$and $B=\theta'(0)$ are assumed values to be determined based on the boundary conditions.

According standard ADM, $U(y)\ and\ \theta(y)$ can be represented in series form as

$$U(y)=\sum_{n=0}^{\infty}U_n(y),\ \theta(y)=\sum_{n=0}^{\infty}\theta_n(y) \quad (17)$$

So that equation (15 & 16) can be written as:

$$\sum_{n=0}^{\infty}U_n(y)=ya+L^{-1}\lambda(1-\lambda\theta)u'\theta'-Gr\theta(1+2\lambda\theta) \quad (18)$$

$$\sum_{n=0}^{\infty}\theta_n=1+yb+L^{-1}\varepsilon\theta'^2(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]-4L^{-1}R(\theta+\phi)^2\theta'^2(1-\varepsilon\theta)[(1+\varepsilon\theta)1-4R(1-\varepsilon\theta)(\theta+\phi)^3]+L^{-1}H\theta(y)(1+\varepsilon\theta)[(1+\varepsilon\theta)1-4R(1-\varepsilon\theta)(\theta+\phi)^3]+L^{-1}Br(1-\lambda\theta(y))u'(y)(1+\varepsilon\theta) \quad (19)$$

We set

$$U_0(y)=yA\ ,\theta_0(y)=1+yB \quad (20)$$

$$U_{n+1}(y)=\lambda L^{-1}(A_n)-GrL^{-1}(B_n) \quad (21)$$

$$\theta_{n+1}(y)=\varepsilon L^{-1}(C_n)-4RL^{-1}(D_n)+HL^{-1}(E_n)+BrL^{-1}(F_n), \quad (22)$$

Where

$$A_n=(1+\lambda\theta)u'\theta'$$
$$B_n=(1+2\lambda\theta)\theta'$$
$$C_n=\theta'^2(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]$$
$$D_n=\theta'^2(\theta+\phi)^2(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]$$
$$E_n=\theta'(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]$$

$F_n = U'^2(y)\big(1-\lambda\theta(y)\big)(1+\varepsilon\theta)[1-4R(1-\varepsilon\theta)(\theta+\phi)^3]$ (23)

The component A_n, B_n, C_n, D_n, E_n *and* F_n for $n \geq 0$ are the Adomian polynomials representing the nonlinear terms which are to be determined using the following ADM relation:

$X_n = \frac{1}{n!}\left[\frac{d^n}{dp^n}\left(N(\sum_{n=0}^{\infty} P^n U_n)\right)\right]_{p=0}$ (24)

RESULTS AND DISCUSSION

The algorithm (20 - 26) is coded into computer algebra package of Maple and is simulated under the influence of the changing physical quantities λ, ε, Pr *Ec*, ϕ , R_T and *Br*. For the purpose of this discussion the values for λ and ε are chosen greater than one. This indicates that the fluid considered in this model is liquid which is in conformity to the fact that viscosity and thermal conduction of liquids decreases with growing temperature. In light of this, the values for Pr are selected as 0.015, 4.0 and 7.0 which corresponds to important fluids as mercury, R-12 refrigerant and water (at 20°C) respectively. The numerical value for ϕ and Da are picked arbitrarily while that of R_T is carefully selected to avoid system burst. In addition; the value for *Br* is chosen greater than one (i.e. *Br* >1) in order to add dissipative effect into the model. In consideration of these assumptions results are presented on tables and graphs with discussion followed.

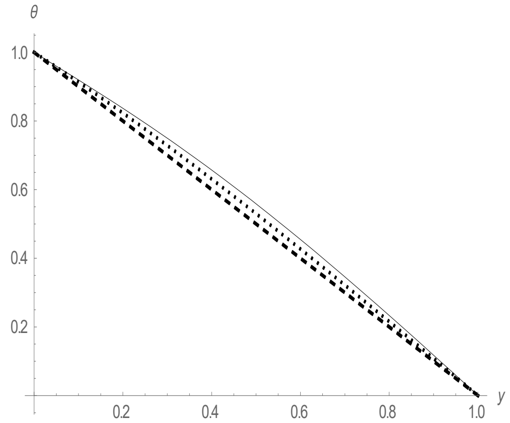


Figure 1: Temperature profiles for different R_T

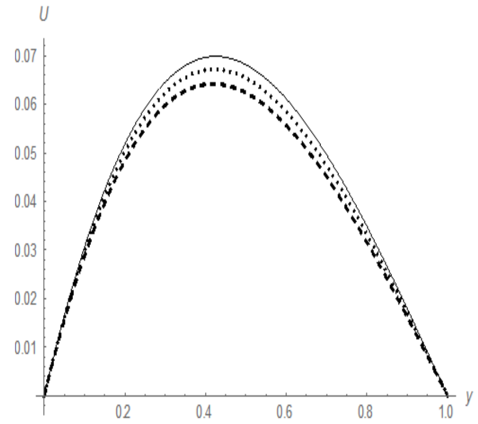


Figure 2: Velocity profiles for different R_T

$R_T(\phi = 0.1, \mathrm{Br} = 0.001, \mathrm{Pr} = 0.015,(\phi = 0.1,\ \lambda = 0.001, \mathrm{Br} = 0.001, \mathrm{Pr} = 0.015, \epsilon = 0.001,\ \lambda = 0.001, \epsilon = 0.001, - -$ R_T= 0.001,. . . R_T = __- - - - R_T = 0.001,. . . R_T = 0.1, ____ R_T= 0.6) ____ R_T= 0.6)

The effect of changing thermal radiation on the thermodynamics and hydrodynamics characteristics across the channel is demonstrated in Figures 2 and 3 above. The figures show that both temperature and velocity increases with increase in R_T. These behaviors are the consequential effect of the decrease in thermal conduction of the fluid which boost the difference between the initial fluid temperature and the wall temperature which as a result increases the buoyancy force of the fluid molecules within the channel.

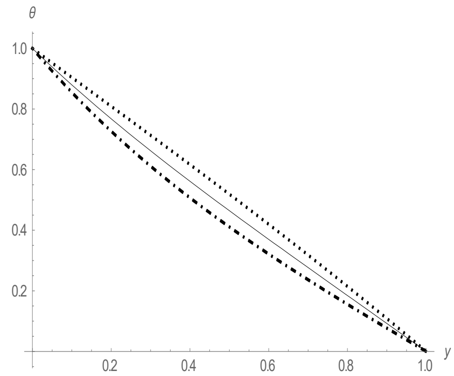


Figure 3: Temperature profiles for different ϕ

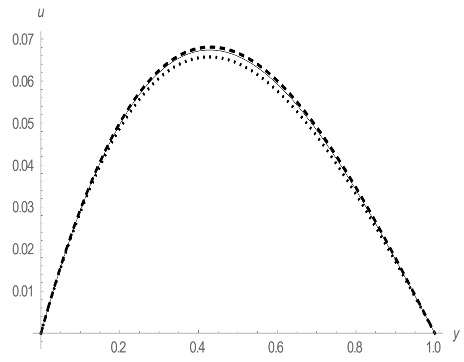
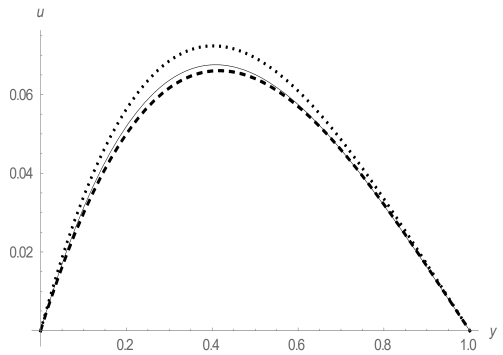


Figure 4: Velocity profiles for different ϕ: profiles for different

$(R_T = 0.1, \mathrm{Br} = 0.001, \mathrm{Pr} = 0.015, (R_T = 0.1, \lambda = 0.001, \mathrm{Br} = 0.001, \mathrm{Pr} = 0.015, \lambda = 0.001, \epsilon = 0.001, -.-\phi = 0.1,$ $\epsilon = 0.001, -.-\phi = 0.1,$____$\phi = 0.5, \ldots$ ____$\phi = 0.5, \ldots\ldots\ \phi = 1)$ . . . .$\phi = 1)$

Figures 4 and 5 demomstrate the influence of fluctuating temperature difference (ϕ) on the flow and energy vehavior within the channel. Both the temperature and velocity are witnessed from the figures to increase with increase in ϕ. These cultures are the influence of the decrease in the difference between wall temperature and the ambient temperature of the fluid. In other words, increase im the ambient fluid temperature helps in strengthening the convection current of the fluid and hence it increases the mobility of the fluid molecules within the channel.



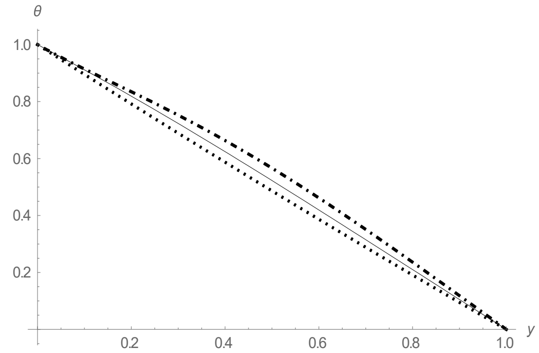
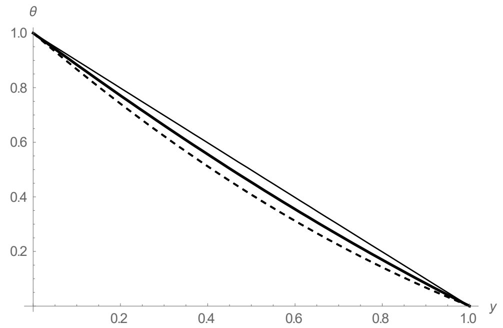


Figure 5: Velocity profiles for different λ Figure 6: Temperature profiles for different λ
($\phi = 0.1, R_T = 0.1, \mathrm{Br} = 0.001, \mathrm{Pr} = 0.015,$ ($\phi = 0.1,\ R_T = 0.1, \mathrm{Br} = 0.001, \mathrm{Pr} = 0.015, \epsilon = 0.001, - - \lambda = 0.2, \epsilon =$ 0.001, ...λ =0.2,___$\lambda = 0.4$,. . . . .$\lambda = 0.8$)_____λ =0.4, -.-.-.-.λ =0.8)

The trends exhibited by the decrease in viscosity of the fluid on the velocity and temperature are described in Figures 6 and 7. It is shown from these Figures that the velocity and temperature within the channel increases with increase in λ This fashion is credited to the decrease in the fluid viscosity caused by decrease in viscous force of the fluid and this acts to retard the flow behavior. Thus; temperature distribution is increased near the heated plate while it decreased near the cold plate. Due to this culture, more heat to generated causing heat accumulation and free movement of the fluid molecules and hence increase in the temperature of the fluid as pictured in Figure 7. The philosophy in Figure 7 is also due to decrease in the fluid viscosity caused by increase in thermal diffusivity, leading to the accumulation of heat in the channel.



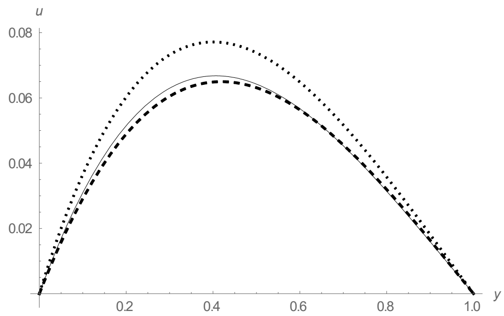
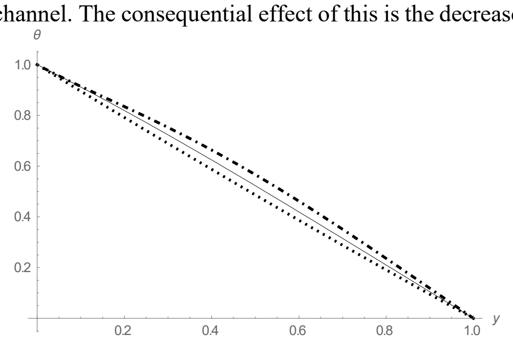


Figure 7: Temperature profiles for different Pr Figure 8: Velocity profiles for different Pr
($\phi = 0.1, R_T = 0.1, \mathrm{Br} = 0.001, \lambda = 0.001,$ ($\phi = 0.1, R_T = 0.1, Br = 0.001, \lambda = 0.001,$ $\mathrm{Da} = 0.001, \epsilon = 0.001$,- - - - Pr=7.0,$\mathrm{Da} = 0.001, \epsilon = 0.001$,- - - -Pr=7.0,_____Pr=4.0,_____Pr=0.015) ____Pr=4.0, ...Pr=0.015)

Figure 8 shows the effect of rising Prandtl number (Pr) on the fluid velocity. It presents an inverse relationship on the temperature of the fluid. As Pr increases, thermal diffusion decreases thereby causing a decrease in the heat flux within the channel. The consequential effect of this is the decrease in velocity as graphed in Figure 9, where the fluid velocity is also seen to decrease with growing Pr. This is attributed to the weakening of convection current caused by decrease in temperature.



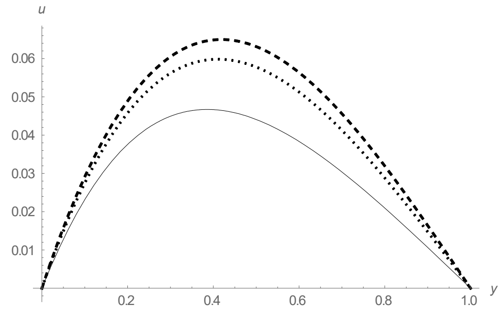


Figure 9: Temperature profiles for different Br Figure 10: Velocity profiles for different Br
($\phi = 0.1, R_T = 0.1, \mathrm{Pr} = 0.015, \lambda = 0.001,$ ($\phi = 0.1, R_T = 0.1, \mathrm{Pr} = 0.015, \lambda = 0.001, \mathrm{Da} = 0.001, \epsilon = 0.001$,- - - - Br =2 $\mathrm{Da} = 0.001, \epsilon = 0.001$,- - - - Br =2, ____ Br =3, . - . - . - Br =4) . . . . Br =3, - - - - - Br =4)

The reflection of upsurge in Brinkman number on the flow is exposed in Figures 10 and 11 respectively. It is understood from the figures that both the temperature and velocity increases with increase in Br. These fashions are due to the production of heat by the molecular conduction caused by viscous dissipation. It also shows that increase in Br produces heat which supersedes the one been transported by the fluid molecules thus; leading to heat accumulation in the channel. As a result of this, the convection current of the fluid is escalated and this weakened the cohesive force of the molecules of the fluid which in return hastened the flow characteristics.

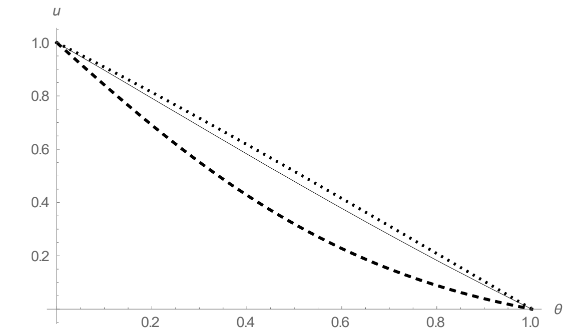


Figure 11:Temperature profiles for different ϵ
($\phi = 0.1, R_T = 0.1, \Pr = 0.015, \lambda = 0.001$, Da $= 0.001$, - - - - - ϵ =0.001, ,______ϵ =0.3, - - - - - - ϵ = 0.6)

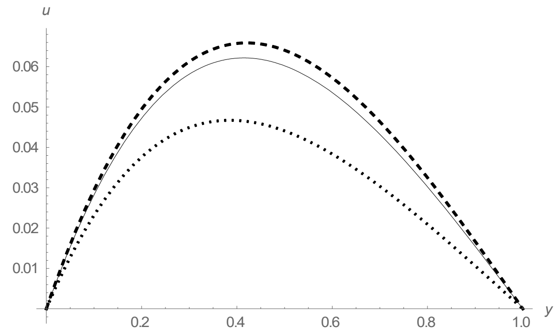


Figure 12:Velocity profile for different ϵ
($\phi = 0.1, R_T = 0.1, \Pr = 0.015, \lambda = 0.001$, Da $= 0.001$,a=0.001 ……$\epsilon = 0.001$ ___ϵ =0.3,. . . . . . . ϵ = 0.6)

Figures 12 and 13 illustrate the effect of escalating thermal conductivity (ϵ) on both the temperature and velocity of the fluid within the channel when other parameters are fixed. From the figures, both the temperature and velocity of the fluid are seen to decrease with increase in ϵ. This physically reveals the effect of decrease in thermal diffusivity of the fluid which act to diminish the influence of the applied boundary temperature and this causes a decrease in the hydrodynamics and thermodynamics characteristics of the fluid.

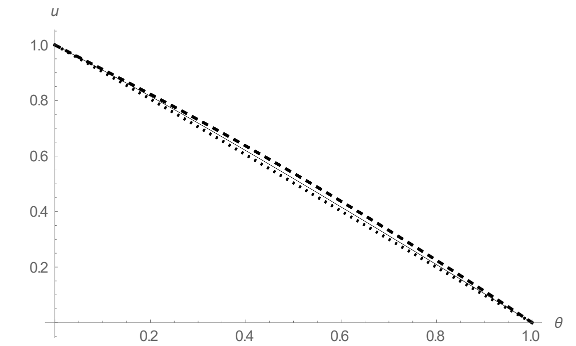


Figure 13:Temperature profiles for different Da
($\phi = 0.1, R_T = 0.1, \Pr = 0.015, \lambda = 0.001, \epsilon$ =0.001, (…… Da $= 0.1$,______Da $= 0.2$, - - -Da $= 0.4$)

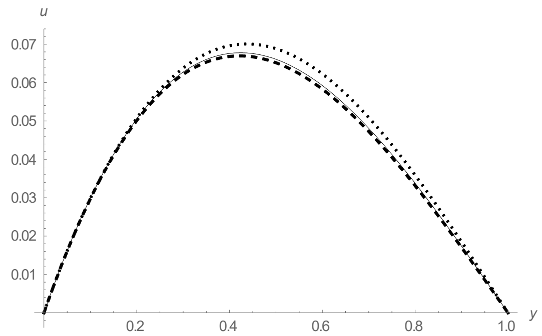


Figure 14:Velocity profiles for different Da
($\phi = 0.1, R_T = 0.1, \Pr = 0.015, \lambda = 0.001, \epsilon$ =0.001, (…… Da $= 0.1$,______Da $= 0.2$,- - -Da $= 0.4$)

Figures 14 and 15 echo the velocity distribution for different Darcy Number (Da). It is clear from the figures that the temperature and velocity decreases with increase in Da. This is the attribute of the increase in the channel porosity and this resulted to the decrease in heat generation within the fluid molecules. This in return weakened the cohesive force between the fluid molecules. The replication of this attitude is the decrease in the fluid velocity as depicted in figure 15.

Table 1: Validation of the Results

	Singh and Paul (2006) R = 0		Present work $a = b = R_T = Br = 0$		Error	
y	$\theta(y)$	$u(y)$	$\theta(y)$	$u(y)$	$\theta(y)$	$u(y)$
0.1	0.900	0.02850	0.90000	0.02819	0.0000	0.00031
0.2	0.800	0.04800	0.800	0.04761	0.0000	0.00039
0.3	0.700	0.05950	0.700	0.05916	0.0000	0..00034
0.4	0.600	0.06400	0.600	0.06377	0.0000	0.00023
0.5	0.500	0.06250	0.500	0.06238	0.00000	0.00012
0.6	0.400	0.05600	0.400	0.05597	0.0000	0.00003

It is clear from the table that the present investigation on suppressing some parameters agreed with that of the published article of Singh and Paul (2006) with insignificant difference.

CONCLUSION

The major findings of this investigation are that a decrease in the fluid viscosity results into an increase in the fluid velocity while an increase in Brinkman results boost the velocity and temperature in the channel. Further extension of this paper is recommended through consideration of unsteady flow with magnetic influence

Table 2: Nomenclature and Greek Symbols

Symbols	Interpretation	Unit
y'	dimensional length	m
y	non-dimensional length	m
t	time	s
g	acceleration due to gravity	ms^{-2}
k	thermal conductivity	W/mK
T	dimensional temperature of the fluid	K
h	width of the channel	m
T_w	wall temperature	K
T_0	ambient temperature	K
V_0	velocity of suction	ms^{-1}
u	dimensionless velocity	ms^{-1}
v	kinematic viscosity of the fluid	m^2s^{-1}
α	thermal diffusivity	
β	volumetric expansion coefficient	K^{-1}
μ	variable viscosity	$kgm^{-1}s^{-1}$
μ_0	Dynamic viscosity of the fluid	$kgm^{-1}s^{-1}$
R_T	Thermal radiation parameter	
q_r	radiative heat flux	Wm^{-2}
θ	dimensionless temperature	K
ϕ	Temperature difference parameter	
U_0	velocity of the moving plate	ms^{-1}
λ	viscosity variation parameter	K^{-1}
R_T	Thermal radiation parameter	
σ	Stefan-Boltzman constant	
$\Re$	Set of real numbers	
δ	Absorption coefficient	
Nu_0	Nusselt number on the plate at $y = 0$	
Nu_1	Nusselt number on the plate at $y = 1$	
τ_0	Skin friction on the plate at $y = 0$	
τ_1	Skin friction on the plate at $y = 1$	
K	permeability of the porous channel	
S	Injection parameter	
V_0	dimensional injection velocity	

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