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IMPACT OF THERMAL RADIATION ON DOUBLE-DIFFUSIVE CONVECTION FLOW OF CASSON FLUID OVER A STRETCHING VERTICAL SURFACE

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ABSTRACT

The present article addresses the double-diffusive convection flow of the Casson fluid with thermal radiation. With suitable independent transformations, the governing partial differential equations are first transformed into ordinary differential equations. The converted equations are solved numerically by using Runge-Kutta-Fehlberg forth-fifth technique (RKF45 Method) via shooting technique. The eects of the emerging parameters, the skin friction coecient, the Nusselt number, and the Sherwood number are analyzed on the dimensionless velocities, temperature, and concentration fields. Outcome shows that buoyancy forces due to temperature difference suppress the skin friction whereas it will enhance the local Nusselt and Sherwood numbers.

Keywords: *Double-diffusive convection, Casson fluid, thermal radiation, vertical surface, Numerical solution.*

1. INTRODUCTION

Heat transfer process with radiation eects is very interesting in electrical power generation, solar system technology, space vehicles, missiles, propulsion devices for aircraft, nuclear plants, astrophysical flows, and many other industrial and engineering applications. Although ample studies were generated for the boundary layer flow in the presence of thermal radiation, the fluid thermal conductivity in such cases is treated as a constant. This perhaps is not realistic because it is now proven that the thermal conductivity of liquid metals varies linearly with temperature from 0^0F to 400^0F Kay(1966). Consequently, the impacts of viscous dissipation and thermal radiation in the stream of a thick liquid over a porous extending sheet were investigated by Cortell (2012). Ramesh et al. (2017) talked about the impacts of thermal radiation on Casson liquid over a stretching sheet within the sight of suspended particles. Hayat and Qasim (2010) analyzed the impact of thermal radiation and Joule heating on MHD flow of a Maxwell liquid within the sight of thermophoresis. Makanda et al (2015) who contemplated the impacts of radiation on MHD free convection of a Casson liquid form a circular cylinder with partial slip in non-Darcy porous medium with viscous dissipation. Run of the mill works can be found in Ramesh (2015); Zheng et al.(2013); Ramesh et al. (2014); Bala and Reddy(2016).

Analysts are giving careful consideration to examine the twofold diffusive blended convection stream as a result of their various mechanical applications, for example, synthetic building, strong state material science, oceanography, geophysics, fluid gas stockpiling, creation of unadulterated medicine, oceanography, superb gem generation, cementing of liquid amalgams and geothermally warmed lakes and magmas and so on. Gaikwad et al (2007) discussed the linear and non-linear double diffusive convection with Soret and Dufour effects in couple stress fluid. Soret and Dufour effect on double diffusion mixed convection from a vertical surface in a porous medium saturated with a non-Newtonian fluid has been carried out by Mahdy (2010). Khan and Aziz (2011) analyzed the double-diffusive natural convective boundary layer flow in a porous medium saturated with a nanofluid over a vertical plate by considering prescribed surface heat, solutal and nanoparticle fluxes. Nield and Kuznetsov (2011) presented the double-diffusive nanofluid convection in a porous medium using analytical method. Abidi et al (2011) carried out the effect of radiative heat transfer on three-dimensional double diffusive natural convection. Subhashini et al (2013). Beg et al (2014), Goyal and Bhargava (2014) are some of the works associated with stretching sheet problem of double diffusive mixed convection.

The decent variety of nature flow builds up the different rheological properties of fluids. The distinctive mechanical procedures like plastic material generation, paints creation, safeguard covering, greases execution and numerous others include the rheological fluids of different qualities. All the rheological parts of fluids can't be portrayed by basic hypothesis of Navier-Stokes. For the correct depiction of rheological fluids, distinctive liquid models like power-law models, Powell-Eyring fluid, Jeffrey, Maxwell and Oldroyd-B liquids, Casson liquid and so forth have been detailed by physical attributes of non-Newtonian materials. The present research managed Casson fluid model which is proposed by suspension of round and hollow formed particles in fluid. Scarcely any normal cases of Casson fluid incorporate blood, waxy unrefined oils, gum arrangements, slurries and so on. This model is appropriate to explore the mechanism of pseudo plastic yield stress liquids. The model is firstly reported by Wilkinson (1960). The various dimensions and aspects of Casson liquid have been explored by Walwander et al. (1975) and Joy (2003). Hayat et al. (2012) presented the analysis of Casson liquid flow under the effects of Dufour and Soret. In another study, Hayat et al. (2012) considered the coupled flow of Casson liquid with mixed boundary condition. Bhattacharyya (2013) elaborated stagnation point Casson fluid flow with heat transport. Impact of entropy generation in Casson nanoliquid flow due to moving surface has been addressed by Abolbashari et al. (2015). Maity et al. (2016) discussed three-dimensional time-dependent flow of Casson liquid with

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injection/suction. Abbas et al. (2016) computed numerical solutions to discuss the chemically reactive flow of Casson fluid with solar radiation. Ganesh Kumar et al. (2017) numerically evaluated the three dimension flow of Oldroyd nanoliquid inspired by viscous dissipation effect. Some recent contributions through Casson fluid for different geometry can be seen in Ul Haq et al. (2014); Venkateswarlu and Satya Narayana (2016); Subba Rao et al. (2016); Ganesh Kumar et al. (2017); Amanulla et al. (2017);.

The fundamental goal of the present examination is to think about the impact of thermal radiation on double diffusive normal convection stream of Casson liquid past an extending vertical surface. The technique for arrangement includes closeness change which decreases the fractional differential conditions into an arrangement of non-direct conventional differential conditions. These non-direct common differential conditions have been comprehended by applying Runge-Kutta-Fehlberg forward fifth request strategy (RKF45 Method) with help of shooting system. The speed and temperature profiles for various estimations of stream parameters are displayed in the figures. It is seen from all assumes that the limit conditions are fulfilled asymptotically in every one of the cases which bolster the precision of numerical outcomes.

2. MATHEMATICAL ANALYSIS

A steady two dimensional laminar mixed convection flow over a stretching vertical surface in a viscous fluid of temperature T_∞ and concentration C_∞ (see Fig. 1) is considered. The stretching velocity is assumed to be of the form $u_w(x) = b\sqrt{x}$ where b is constant with $b>0$, T_W and C_W are temperature and concentration at the wall assumed to be constant. The buoyancy forces arise due to the variations in temperature and concentration of fluid. The Boussinesq approximation is invoked for the fluid properties to relate the density changes to temperature and concentration and to couple in this way the temperature and concentration fields to the flow field. Under these assumptions, the governing boundary layer equations can be expressed as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon(1+\frac{1}{\beta})\frac{\partial^2 u}{\partial y^2} + g\beta^*(T - T_\infty) + g\beta^{**}(C - C_\infty) \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} \tag{4}$$

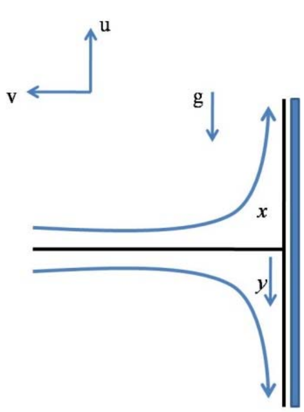

Fig. 1 Schematic diagram of the problem

with the relevant boundary conditions

$$u{=}u_W,\ v{=}0,\ T{=}T_W,\ C{=}C_W \text{ at } y = 0$$
$$u{=}0,\ T{\to}T_\infty,\ C{\to}C_\infty \text{ at } y \to \infty \tag{5}$$

Using the Rosseland approximation for radiation, radiation heat flux q_r is simplified as,

$$q_r = -\frac{4\sigma^* \partial T^4}{3k^* \partial y} = -\frac{16\sigma^*}{3k^*}T_\infty^3\frac{\partial T}{\partial y} \tag{6}$$

where σ^* and k^* are the Stefan – Boltzmann constant and the mean absorption coefficient respectively.

In view to Eq. (6), Eq. (3) reduces to

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{\partial}{\partial y}\left[\left(\alpha + \frac{16\sigma^* T_\infty^3}{3k^*}\right)\frac{\partial T}{\partial y}\right] \tag{7}$$

The following similarity transformations are introduced to Eqs. (1)–(4),

$$\varphi = (\upsilon x u_w(x))^{\frac{1}{2}} f(\eta), \theta(\eta) = \frac{T - T_\infty}{T_W - T_\infty}$$

$$\phi(\eta) = \frac{C - C_\infty}{C_W - C_\infty}, \quad \eta = \left(\frac{u_W(x)}{\upsilon x}\right) \tag{8}$$

where φ is the stream function defined in the usual form as,

Eq. (1) is identically satisfied and the velocity components u and v are given by

$$u = u_w(x) f'(\eta), \quad v = -\frac{1}{4}\left(\frac{u_W(x)}{\upsilon x}\right)(3f - \eta f') \tag{9}$$

where prime denotes differentiation with respect to η. Therefore, substituting the new variables (8) and (9), Eqs. (2)–(4) are reduced to the following set of ordinary differential Eqs.,

$$\left(1+\frac{1}{\beta}\right)f''' + \frac{3}{4}f''f - \frac{1}{2}f'^2 + \lambda(\theta + N\phi) = 0 \tag{10}$$

$$\left(1+\frac{4}{3}R\right)\theta'' + \Pr\frac{3}{4}\theta' f = 0 \tag{11}$$

$$\phi'' + Sc\frac{3}{4}\phi' f = 0 \tag{12}$$

along the transformed boundary conditions (5) are

$$f'(\eta){=}1, f(\eta){=}0\ \theta(\eta){=}1, \phi(\eta){=}1 \quad \text{at} \quad \eta{=}0$$
$$f'(\eta){=}0,\ \theta(\eta){=}0, \phi(\eta){=}0 \quad \text{as} \quad \eta{\to}\infty \tag{13}$$

where η_∞ is the edge of the boundary layer. Here $\lambda{=}\lambda_1(x)$ is the mixed convection parameter and $N{=}N(x)$ is the buoyancy force parameter, which are given by

$$\lambda_1(x){=}Gr_x,\ N(x){=}\frac{Gr^*}{Gr},$$

with $Gr{=}\frac{g\beta^*(T_W - T_\infty)}{b^2}$ and $Gr^*{=}\frac{g\beta^{**}(C_W - C_\infty)}{b^2}$ are the Grashof numbers and $\mathrm{Re}_x{=}\frac{u_W(x)x}{\upsilon}$ is the local Reynolds number, $\Pr{=}\frac{\upsilon}{\alpha}$ is the Prandtl number, $Sc{=}\frac{\upsilon}{D}$ is the Schmidt number, $R{=}\frac{4\sigma^* T_\infty^3}{k^* k}$ is the radiation parameter. On the other hand, it should be noticed that because $\lambda{=}\lambda_1(x)$ and $N{=}N(x)$, Eqs. (8)–(10) are only locally similarity equations. λ_1 and N will be further considered as constants. It may be noted that $\lambda_1{>}0$ corresponds to assisting flow (the external velocity is opposite to the acceleration due to gravity), $\lambda_1{<}0$ corresponds to opposing flow (the external velocity and the acceleration due to gravity have the same direction) and $\lambda_1=0$ corresponds to force convection flow (non-buoyant case).

The physical quantities of interest are the skin friction coefficient C_f, local Nusselt number Nu_x and the Sherwood number Sh_x as defined by,

$$C_f=\mu\left(\frac{\partial u}{\partial y}\right)_{y=0},\quad q_w=-k\left(\frac{\partial T}{\partial y}+q_r\right)_{y=0} \text{ and } j_w=-D_m\left(\frac{\partial C}{\partial y}\right)_{y=0}.$$

Using similarity transformations and we get;

$$C_f(\mathrm{Re}_x)^{\frac{1}{2}}=\left(1+\frac{1}{\beta}\right)f''(0),$$

$$Nu_x(\mathrm{Re}_x)^{-\frac{1}{2}}=\left[1+\frac{4}{3}R\right]\theta'(0)$$

and $Sh_x(\mathrm{Re}_x)^{\frac{1}{2}}=-\phi'(0)$.

3. RESULTS AND DISCUSSION

The arrangement of coupled to a great degree non-direct conventional differential conditions (10)–(12) subject to the boundary conditions (13) is settled numerically utilizing Runge-Kutta-Feldberg 45 procedure. In algebraic package Maple, the Shooting method is implemented as an algorithm called ‘shoot’. This Maple software has been well tested for its accuracy and robustness and this has been used to solve a wide range of non-linear problems. It is most important to choose an appropriate finite value of η_∞. In this method, a suitable finite value of η_∞ is considered as η_6 in such way that the boundary conditions defined at infinity satisfy asymptotically. In addition, the relative error tolerance to 10^{-6} is considered for convergence and the step size is chosen as $\Delta\eta = 0.001$. Table 1 shows the comparison of the present numerical solution with the previous results for various values of Pr. One can see that our solutions have complete agreement with the existing solutions in a limiting sense. Complete numerical parametric calculations are done for different physical parameters esteems then the outcomes are accounted for as far as charts. Numerical arrangements got for the issue are communicated as far as charts for different reaches and for different decisions of the stream parameters. Effect of radiation parameter, Schmidt number, Prandtl number, mixed convection parameter, buoyancy parameter, non-Newtonian Casson parameter on rate, temperature and focus profiles are specified.

Figs. 2-4 shows the varieties of velocity, temperature and concentration profiles for various estimations of Casson parameter (β). From Fig. 2, we have a tendency to verify that the velocity profile diminishes once an expanding β. An elevating the estimations of β, prompts an expansion in unique thickness that produces protection inside the flow of liquid and a reduction in liquid velocity is resolved. Figs. 3 and 4 shows that the bigger estimations of Casson parameter deliver a change inside the temperature profile, concentration profile and related boundary layer thickness.

Figs. 5-7 shows the effect of mixed convection parameter (λ) on velocity, temperature and concentration profiles. Velocity profile and boundary layer thickness increment for the higher estimations of mixed convection parameter λ as appeared in Fig. 5. In Figs. 6 and 7, it's determined that the increase in λ causes a reduction in temperature, concentration profiles and additionally as thermal boundary layer thickness.

The effect of buoyancy parameter (N) for velocity, temperature and concentration profiles is shown in Figs. 8-10. Here both the velocity and boundary layer thickness increment for expanding N. Be that as it may, on account of temperature and concentration profiles raises the buoyancy parameter its displays inverse conduct of the velocity profile. The after effect of radiation parameter (R) on the temperature profile is given in Fig. 11.

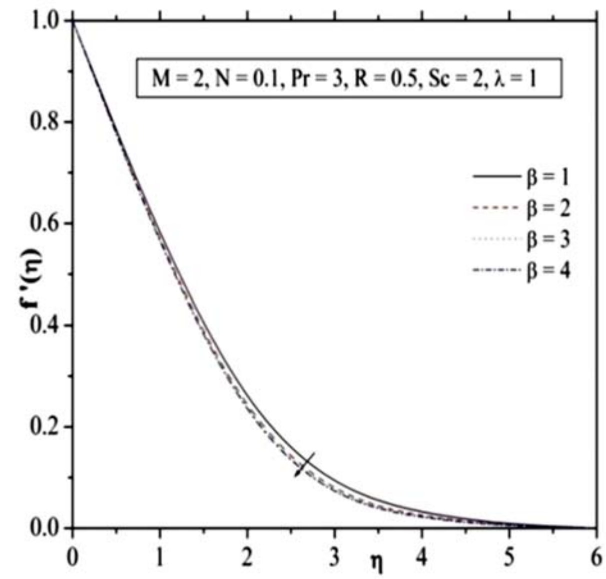

Fig. 2 Velocity profile for Casson parameter.

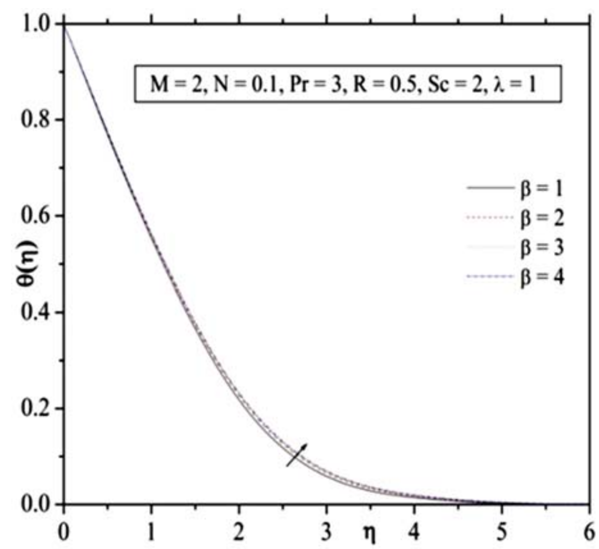

Fig. 3 Temperature profile for Casson parameter.

Table-1: Comparison of $-\theta'(0)$ for different values of Prandtl number Pr when $R=\lambda=\theta_w=0$ and $D_f=0$.

Pr	Chen (1998)	Present result
1.0	-0.58199	-0.58223
3.0	-1.16523	-1.16522
5.0	-	-1.56803
10.0	-2.30796	-2.30798
100.0	-	-7.76564

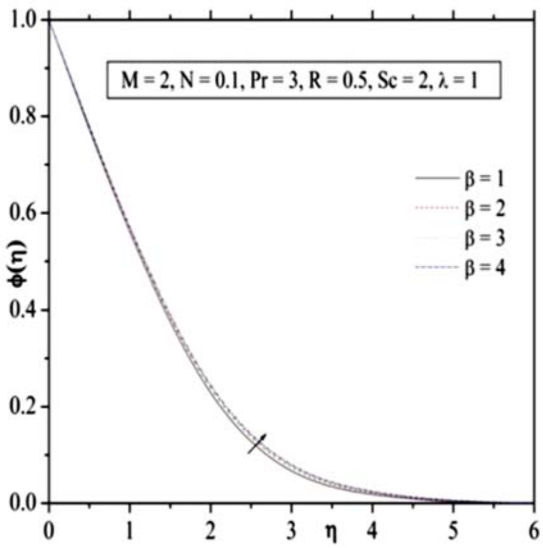

Fig. 4 Concentration profile for Casson parameter.

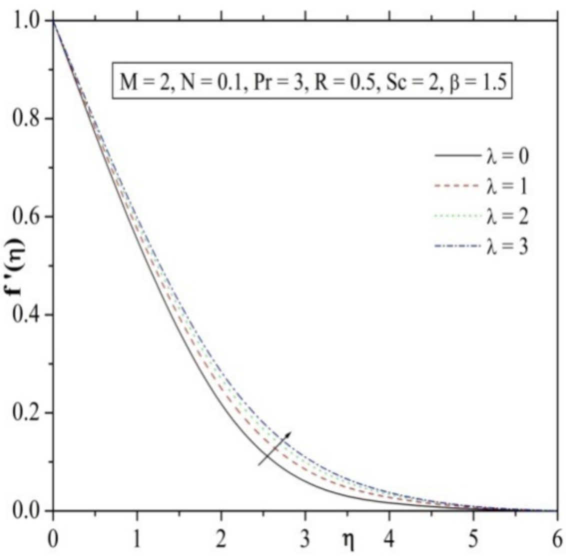

Fig. 5 Velocity profile for mixed convection parameter.

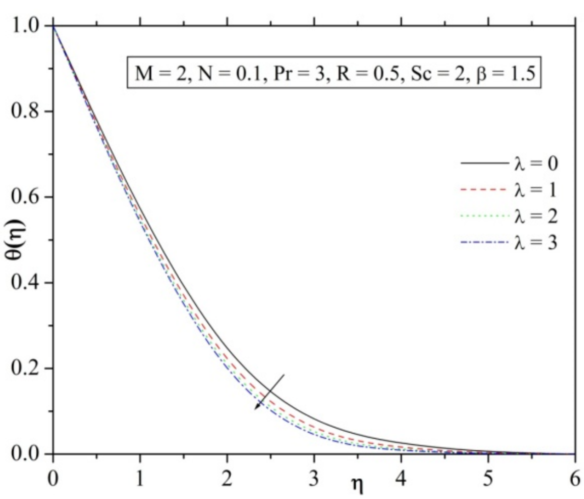

Fig. 6 Temperature profile for mixed convection parameter.

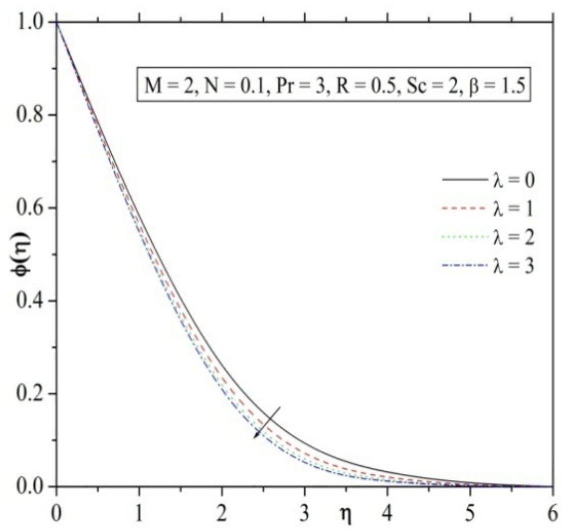

Fig. 7 Concentration profile for mixed convection parameter.

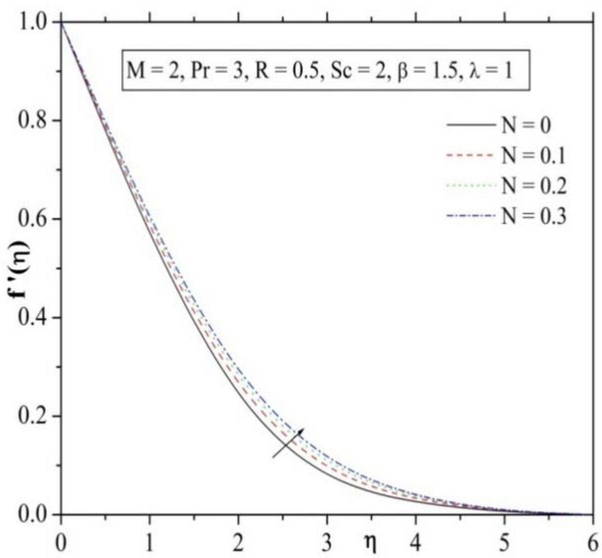

Fig. 8 Velocity profile for buoyancy force parameter.

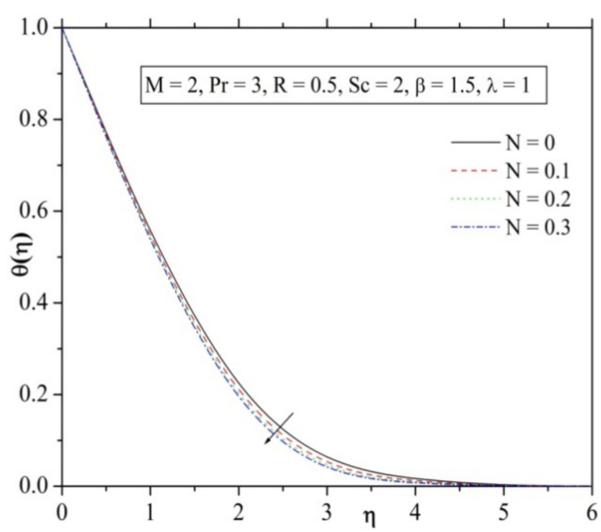

Fig. 9 Temperature profile for buoyancy force parameter.

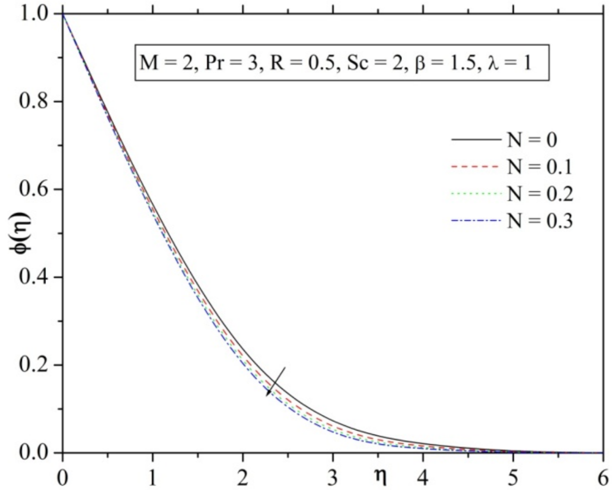

Fig. 10 Concentration profile for buoyancy force parameter.

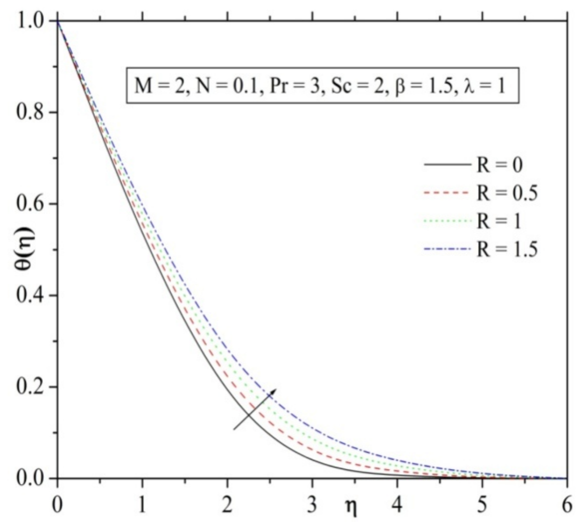

Fig. 11 Temperature profiles for R.

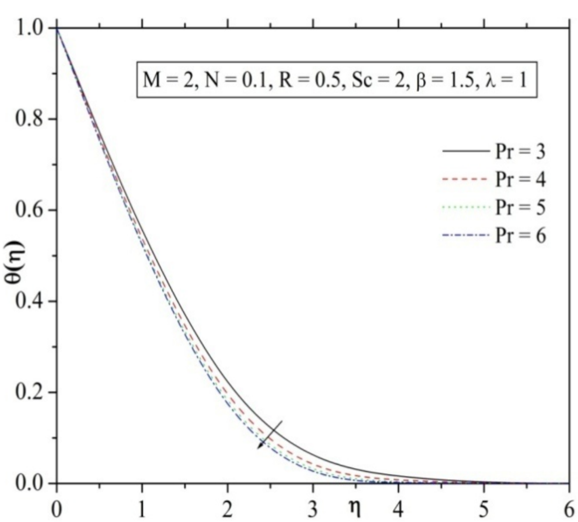

Fig. 12 Temperature profiles for $\Pr$.

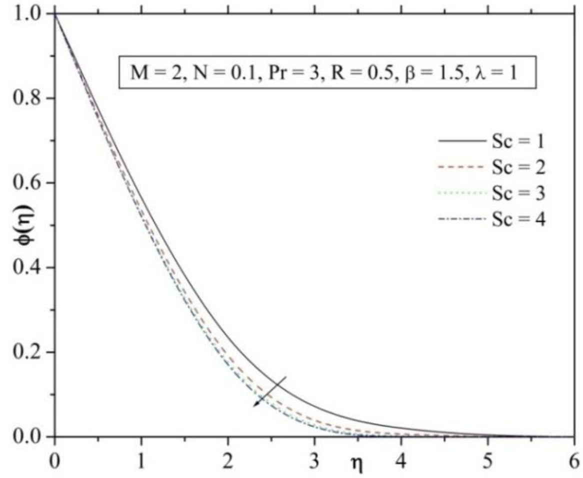

Fig. 13 Concentration profile for Schmidt number.

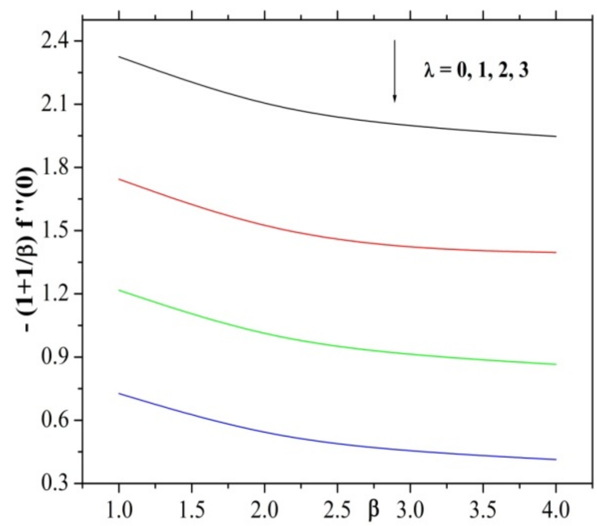

Fig. 14 Skin friction coefficient for λ verses β.

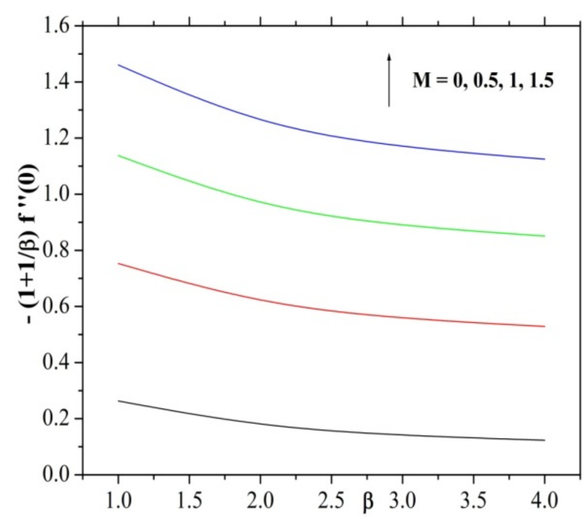

Fig. 15 Skin friction coefficient for M verses β.

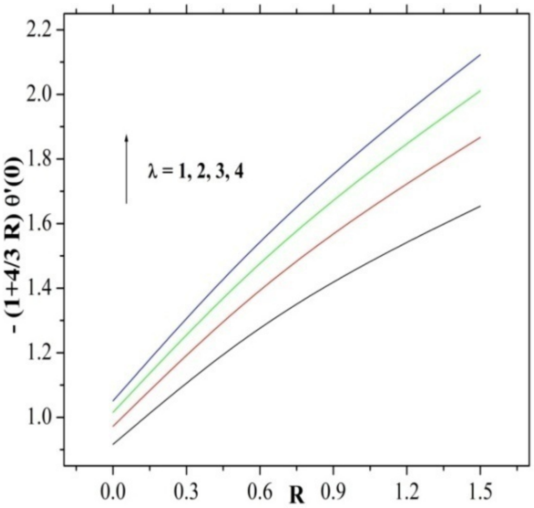

Fig. 16 Nusselt number for λ verses R.

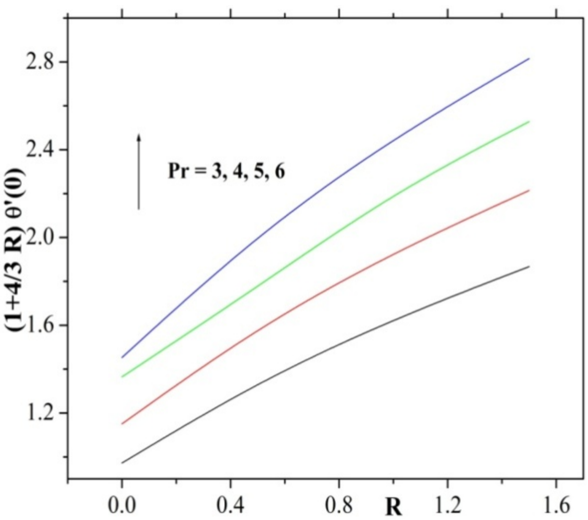

Fig. 17 Nusselt number for $\Pr$ verses R.

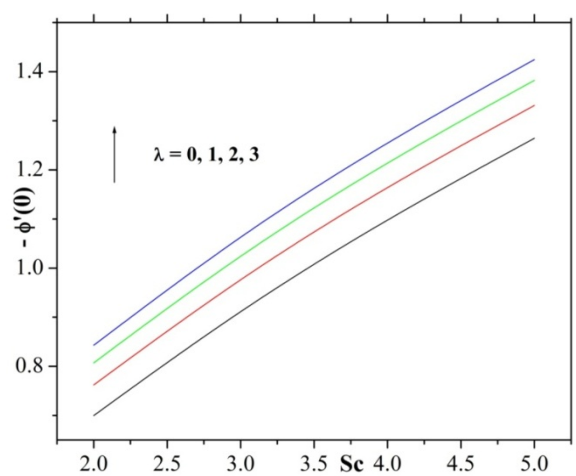

Fig. 18 Sherwood number for λ with Sc.

From this figure we have a tendency to watch that, as the estimation of R expands the temperature profiles will increment, moreover an expanding in the thermal boundary layer thickness. Fig. 12 demonstrates the variety of the temperature profile for various estimations of Prandtl number $(\Pr)$. The outcome demonstrates that an increments of Prandtl number prompts a diminishing the thermal boundary layer thickness. The reason is that littler estimations of are like expanding the thermal conductivities, thus heat is prepared to contrast far from the heated surface snappier than for higher estimations of $\Pr$. Subsequently, the boundary layer is thicker and furthermore the rate of heat exchange is decreased, for slope are diminished. Fig.13 demonstrates the concentration profiles over the physical marvel for various estimations of Schmidt number (Sc). The figure demonstrates that an expanding Sc in prompts a diminishing the focus circulations, as an aftereffects of the littler estimations of Sc are reminiscent of expanding the chemical molecular diffusivity.

Fig. 14 show the relation between mixed convection parameter and Casson parameter, which is proportional to skin friction coefficient. This figure depicts that the skin friction coefficient increases with an increasing λ and β parameter. The local skin friction coefficient increases by increasing β and M as show in Fig. 15. Figs. 16 and 17 shows the impact of λ and $\Pr$ with the various value of R respectively for Nusselt number. The local Nusselt number is an increasing behaviour for higher values of the mixed convection parameter versus radiation parameter and the Prandtl number versus radiation parameter. Fig. 18 illustrates the variations in the mixed convection parameter and Schmidt number on Sherwood number. From this figure it's clear that an increase λ and Sc will increase the Sherwood number.

4. CONCLUSIONS

Investigation of thermal radiation on double diffusive convection Casson liquid flow over an stretching vertical surface is displayed. Numerical outcomes for velocity profiles, surface heat transfer rate and mass transsfer rate are acquired for steady varieties of changed reaches and for the different estimations of flow related parameters. The most results of the issue are condensed as takes after;

- Casson parameter increment the velocity profile while lessening the temperature and concentration profiles.
- Buoyancy force because of temperature contrast lessens the skin erosion though will expand the neighborhood Nusselt and Sherwood numbers.
- Expanding the mixed convection parameter will build speed, nearby Nusselt number and neighborhood Sherwood number and declines the skin rubbing coefficient, temperature and concentration profiles.
- Higher Schmidt number caused the decreases in concentration boundary layer thickness.
- Thermal layer thickness increment by expanding the radiation parameter yet inside the instance of Prandtl number it displays inverse conduct of radiation parameter.

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NOMENCLATURE

c	Concentration (kg/m^3)
c_p	Specific heat (J/kg K)
c_w	concentration at wall
c_∞	ambient concentration

D	mass diffusivity
f	dimensionless stream function
g	dimensionless velocity
Gr_x, Gr_x^*	local Grashof numbers
k	thermal conductivity $(W/m\ K)$
N	ratio of buoyancy parameters
Nu_x	Local Nusselt number
Pr	Prandtl number
R	radiation parameter
Sc	Schmidt number
T	temperature of the fluid (K)
T_w	uniform temperature (K)
T_∞	ambient temperature (K)
u_w	constant velocity
u,v	velocity components of the fluid along x and y directions
x,y	Cartesian co-ordinates

Greek Symbols

α	thermal diffusivity (m^2/s)
β	Casson parameter
β^*	volumetric coefficient of thermal expansion
β^{**}	volumetric coefficient of expansion for concentration
ρ	density of the base fluid (kg/m^3)
ν	kinematic viscosity of the fluid (m^2/s)
σ^*	Stefan-Boltzmann constant $(W/m^2\ K^4)$
θ	dimensionless fluid temperature
μ	viscosity of the fluid $(N\ s/m^2)$
η	similarity variable

Subscripts

w	at the wall
∞	ambient temperature

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