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Combined Convection Stagnation-Point and Transfer of Heat of a Jeffery Fluid

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Abstract:

The impact of heat radiation on the combined point flow and convection stagnation over an expanding surface is discussed in the study. The nonlinear momentum and energy equation is shown to be the controlling one. We characterize the amount of heat transfer that takes place by using the Rosseland approximation. MATLAB is employed solve the ODE that are obtained from the reduced partial differential equations through the application of similarity transformations. Graphs for each scenario are used to discuss how each of the relevant parameters affects flow and temperature distribution. In a limited sense, a comparison is done with the known numerical solution

Key words: Stagnation point, thermal radiation, Jeffery fluid, combined convection

1. Introduction:

It has been observed in past few years a vast study is being conducted on non-Newtonian fluid flowing fluidly across a stretching sheet and numerous experiments are being conducted to study the fluids at stagnation point and thermal radiation plays a vital role as it has got more uses in gas turbines, nuclear power plants, propulsion devices of aircraft and space vehicles and in several engineering implementation in the process of extrusion, insulating materials, paper production etc. The non-Newtonian fluids are broadly classified into three branches i.e. viscoelastic, time independent and time dependent one among the famous non-Newtonian fluid is Jeffrey fluid. It has got great properties for retardation and relaxation time ratio which are given by the parameters λ_1 and λ_2 resp. because of its viscoelastic behavior. It has got numerous applications in the field of medicine and industry Ramesh K. [1] has studied the impact of viscous dissipation and joule heating on the Couette and Poiseuille flows of a Jeffrey fluid. Nazeer M, Ali N, Ahmad F, et al. [2] investigated on Effects of radiative heat flux and joule heating on electro-osmotically flow of non-Newtonian fluid. Jamil M and Haleem A [3] examined the MHD fractionalized Jeffrey fluid over an accelerated slipping porous plate., Bhatti MM and Zeeshan [4] studied on variable magnetic field on the peristaltic flow of Jeffrey fluid in a non-uniform rectangular duct with compliant walls [5-10] examined the various studies on Jeffrey fluid models. Hayat T, Asghar S, Tanveer A, et al [11] examined the Chemical reaction in peristaltic motion of MHD couple stress fluid in channel with Soret and Dufour effects. Ramesh K and Devakar M. [12] gave the Effects of heat and mass transfer on the peristaltic transport of MHD couple stress fluid through porous medium in a vertical asymmetric channel. J Fluids. Hassan M, Ellahi R, Bhatti MM, et al [13]. has given a comparative study of magnetic and non-magnetic particles in nanofluid propagating over a wedge. Khan NA, Khan H and Ali S. [14] gave Exact solutions for MHD flow of couple stress fluid with heat transfer. Srinivas S and Gayathri R. [15] examined the Peristaltic transport of a Newtonian fluid in a vertical asymmetric channel with heat transfer and porous medium. Nield DA and Bejan A [16]. studied the Convection in porous media. Ellahi R, Riaz A, Nadeem S, et al. [17] studied the Peristaltic flow of Carreau fluid in a rectangular duct through a porous medium. T. Hayat, M. Awais, M. Qasim, and A. A. Hendi [18] investigated the Effects of mass transfer on the stagnation point flow of an upper-convected Maxwell (UCM) fluid T. Hayat, M. Qasim [19] examined the Radiation and magnetic field effects on the unsteady mixed convection flow of a second-grade fluid over a vertical stretching sheetT. Hayat, M. Qasim[20]studied the Influence of thermal radiation and Joule heating on MHD flow of a Maxwell fluid in the presence of thermophoresis .I. A. Hassanien *et al.[21] investigated the* Combined forced and free convection in stagnation flows of micropolar fluids over vertical non-isothermal surfaces .F.R. de Hoog *et al.[22]* they discussed a numerical study of similarity solutions for combined forced and free convection .N. Ramachandran *et al.* [23] they considered the Mixed convection in stagnation flows adjacent to a vertical surfaces. Masarath Jabeen, V Dhanalaxmi [24-25] discussed the Transfer of heat and mass of a Jeffrey Fluid over a linearly stretching sheet with chemical reaction: Numerical study and Combined Effect of Viscous Dissipation and Ohmic Heating on MHD Jeffrey Nanofluid Flow with Magnetic Dipole Effect A Ishak, R. Nazar, N. Bachok, et al [26] examined the MHD mixed convection flow near the stagnation-point on a vertical permeable surface Tasawar Hayata, Sabir Ali Shehzad, Muhammad Qasim, and Saleem Obaidat et al [27] studied the Thermal Radiation Effects on the Mixed Convection Stagnation-Point Flow in a Jeffery Fluid Hayat T, Naeem I, Ayub M, Siddiqui AM, Asghar S, Khalique CM.[28] they discussed the exact solutions of second grade aligned MHD fluid with prescribed vorticity. Asghar S, Hayat T, Ariel PD. [29] investigated the Unsteady Couette flows in a second-grade fluid with variable material properties. Fetecau C, Zierep J. [30] investigated on a class of exact solutions of equations of motion of a second-grade fluid. Ishak A, Nazar R,[31] they discussed the Hydromagnetic flow and heat transfer adjacent to a stretching vertical sheet. Abbas Z, Hayat T, Sajid M, Asghar S. [32] studied the Unsteady flow of a second-grade fluid film over an unsteady stretching sheet. By considering the applications mentioned above, we analyzed Combined Convection stagnation-point and transfer of heat of a Jeffery fluid The nonlinear momentum and energy equation is shown to be the controlling one. We characterize the amount of heat transfer that takes place by using the Rosseland approximation. The effects of all involved parameters on flow and temperature distributions are deliberated with the help of graphs

Mathematical analysis

The essential equations for Jeffrey fluid can be written as

$$\tau = -pl + \mathrm{E} \tag{1}$$

$$\mathrm{E} = \frac{\mu}{1+\lambda_1}\left[R_1 + \lambda_2\left(\frac{\partial R_1}{\partial t} + V.\Delta\right)R_1\right] \tag{2}$$

Where E is the extra stress tensor, τ is the Cauchy stress tensor, $\lambda_1$and $\lambda_2$are the material parameters of Jeffrey fluid and R_1 is the Rilin -Ericksen tensor defined by

$$R_1 = (\nabla V) + (\nabla V)'$$

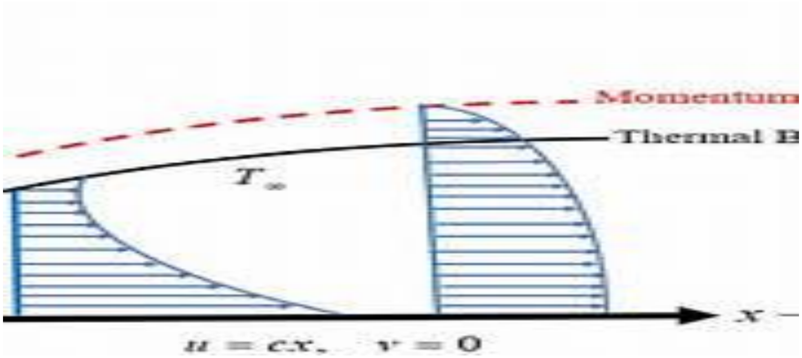


fig 1 physical representation of the flow

Consider a two-dimensional Jeffery fluid passage at the stagnation point under the impact of thermal radiation in the half space Z> 0. The sheet in the XOY plane is stretched in the x-direction such that the velocity component in x-direction varies linearly along it. The fluid flows with certain velocity ax, considering the heat transfer effects. The concentration and the velocity are $T_w(x)$, $u_w(x)$ respectively of the stretching sheet are proportional to the distance x from the stagnation-point, where $T_w(x) > T_\infty$. In the absence of viscous dissipation, the equations governing the boundary layer flow can be written as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U_\infty\frac{\partial U_\infty}{\partial x} + \frac{v}{1+\lambda_1}\left[\frac{\partial^2 u}{\partial y^2} + \lambda_2\left(u\frac{\partial^3 u}{\partial x\partial y^2} + v\frac{\partial^3 u}{\partial y^3} - \frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial x\partial y}\right)\right] + g\gamma_T(T - T_\infty) \tag{4}$$

Where u, v are taken as the velocity elements within the in the x and y direction respectively,υ is the kinematic viscosity, λ_1 is the relaxation ratio and retardation time,λ_2 is the relaxation time. γ_T the thermal expansion coefficient, g the gravitational acceleration The heat transfer equation under thermal radiation is given as

$$\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = k\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} \tag{5}$$

By using Rosseland diffusion roughly speaking, the amount of heat transfer that takes place

q_r is given by

$$q_r = -\frac{4\sigma^*}{3K_s}\frac{\partial T^4}{\partial y} \tag{6}$$

Where α is thermal diffusivity K_s and σ^* are the Rosse land mean absorption coefficient and the Stefen-Boltzmann constant, resp. the temperature within the fluid flow is almost negligible such that T^4can be expressed as linear function of temperature.

$$T^4 \approx 4{T_\infty}^3 T - 3{T_\infty}^4 \tag{7}$$

On solving (6) (7) and (5) we get

$$\frac{\partial q_r}{\partial y} = -\frac{16\sigma^* {T_\infty}^3}{3K_s}\frac{\partial^2 T}{\partial y^2} \tag{8}$$

We introduce a dimensionless temperature variable $\theta(\xi)$ of the form

$$\theta(\xi) = \frac{T - T_\infty}{T_w - T_\infty} \tag{9}$$

The eq (5) takes the form

$$\rho c_p \left(u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y}\right) = \frac{\partial}{\partial y}\left[\left(\frac{16\sigma^* {T_\infty}^3}{3K_s} + k\right)\frac{\partial T}{\partial y}\right] \tag{10}$$

Where c_p is the specific heat and k is the conduction coefficient, T denotes the heat of the fluid.T_∞ is the constant heat of the fluid at a faraway point from the sheet.

Boundary Conditions:

The boundary conditions on rapidity, heat and mass are appropriate in order to employ the result of stretching of the boundary surface causing flow in *x*-direction as

$$u = U_w(x) = cx, v = v_w(x)$$

$$u \to 0, u' \to 0 \; as \; y \to \infty$$

$$T = T_w(x) = T_\infty + bx \text{ at y=0}$$

$$u = U_\infty(x) = ax \tag{11}$$

$$\text{T} \to T_\infty \text{as y} \to \infty$$

$$v_w(x) = -\sqrt{cv}\, S \tag{12}$$

Where The heat of the spread sheet is T, the subscript w and ∞ has been used for the walls and far away from the wall, resp.

with $f(0) = S$ (with S > 0 for suction and S < 0 for injection), c is a stretching rate

The subsequent similarity variations are proposed to solve equation (4) and (10)

$$u = cxf'(\xi), v = -\sqrt{cv}f(\xi) \;\; where \; \xi = \sqrt{\frac{c}{v}}y \tag{13}$$

Where ξ is the variable of similarity and $f(\xi)$ is the dimensionless stream function

Substituting eq (13) in eq (4) and (10) we obtain Ordinary differential equations of second and fourth order

as follows

$$f''' + (1+\lambda_1)\left(ff'' - {f'}^2\right) + \beta\left({f''}^2 - ff^{iv}\right) + (1+\lambda_1)\frac{a^2}{c^2} + (1+\lambda_1)\lambda\theta = 0 \tag{14}$$

$$\left(1 + \frac{4R}{3}\right)\theta'' + \Pr(f\theta' - f'\theta) = 0 \tag{15}$$

With boundary conditions:

$$f(\xi) = s, f'(\xi) = 1 \; at \; \xi = 0; f'(\xi) = \frac{a}{c}, f''(\xi) = 0, as \; \xi \to \infty$$

$$\theta(\xi) = 1 \; at \; \xi = 0 \; ; \; \theta(\xi) = 0 \; as \; \xi \to \infty \tag{16}$$

Where $\beta = \lambda_2 c$ is the Deborah number, $R = \frac{4\sigma^* T_\infty{}^3}{K_s}$ the radiation parameter,

$Pr = \frac{\rho c_p}{k}$ the Prandtl number, combined convection parameter $\lambda = \frac{Gr_x}{Re_x{}^2}$, the local Grashof number $Gr_x = \frac{g\gamma_T (T_w - T_\infty) x^3}{v^2}$, the local Reynold number $Re_x = \frac{u_x x}{v}$, and suction parameter s.

The set of equations involving products of the dependent variable and its derivatives (14) (15) with the limiting conditions (16) are converted to linear ODE by applying shooting method and using MATLAB bvp4c the numerical solution is obtained, thus the higher order equations are resolved to system of simultaneous equations of order one.

$$f = y_1, f' = y_2, f'' = y_3, f''' = y_4$$

$$\theta = y_5, \theta' = y_6 \quad (17)$$

Substituting these in (14)(15) and (16) we have

$$y(4) + (1+\lambda_1)\left(y_1 y_3 - y_2{}^2) + (1+\lambda_1)\lambda y_5 + (1+\lambda_1)(\frac{a^2}{c^2})\right) + \beta(y_3{}^2 - y_1 y_4{}') = 0 \quad (18)$$

$$\left(1 + \frac{4R}{3}\right) y_6' - Pr(y_1 y_6 - y_2 y_5) = 0 \quad (19)$$

With boundary conditions

$$y_1(0) = s, y_2(0) = 1, y_5(0) = 1, y_6(0) = 1, y_2(\infty) = \frac{a}{c}, y_3(\infty) = 1, y_5(\infty) = 0$$

Equations (17)(19) are reduced to eight simultaneous equations of first order as follows

$$y_1{}' = y_2$$

$$y_2{}' = y_3$$

$$y'(3) = y(4)$$

$$y'(4) = \frac{1}{\beta y1}\left(y4 + (1+\lambda_1)(y_1 y_3 - y^2{}_2\right) + (1+\lambda_1)\lambda y_5 + (1+\lambda_1)\frac{a^2}{c^2} + \beta y_3{}^2\Big) \quad (20)$$

$$y'(5) = y(6)$$

$$y'(6) = -\frac{Pr}{\left(1+\frac{4R}{3}\right)}(y_2 y_5 - y_1 y_6) \quad (21)$$

$$y_1(0) = s, y_2(0) = 1, y_5(0) = 1, y_6(0) = 1, y_2(\infty) = \frac{a}{c}, y_3(\infty) = 1, y_5(\infty) = 0.$$

The governed equations are solved numerically using MATLAB using bvp4c

Findings and Discussions

Here the impact of combined convection parameter λ, stretching ratio a/c, suction parameter s, Prandtl number Pr, radiation parameter R, Deborah number β, and the parameter λ_1 on the realms of temperature and velocity are shown through graphs

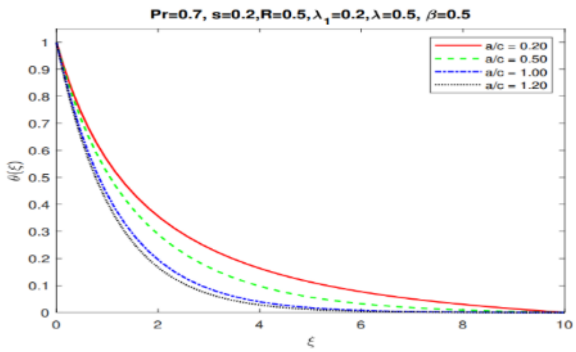
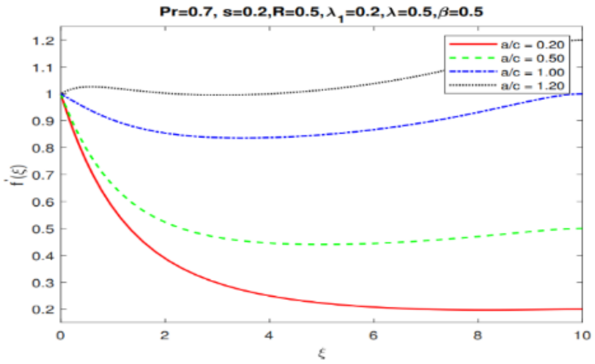


fig (2)



fig(3)

fig(2,3) shows the deflection of stretching ratio with rapidity and heat as the ratio is increasing the rapidity is decreasing whereas heat is just the reverse, fig(4,5) shows the impact of λ on rapidity and heat there is a vide increase in rapidity of the fluid with the rapid change in convection parameter λ,where as the heat decreases with the increase in λ value,fig(6,7) shows the effect of suction parameter s on rapidity and limiting layer are reducing functions of s. The heat limiting layer viscosity also decreases with s. This is quite in accordance with the fact that suction causes reduction in the momentum limiting layer viscosity. The variation of the Prandtl number with rapidity and heat is given in fig (8,9).as known the Prandtl number increases the viscosity of the fluid hence reducing the rapidity of the liquid and it has thinner heat limiting layer this increases the gradient of temperature, the study of radiation parameter is shown in fig (10,11), It can be observed in fig (12,13) that the velocity field and limiting layer viscosity are intensifying functions of β. The heat deplete for higher values of β. As observed in fig. (14,15) that the outcome of λ_1 is opposite to the result of the Deborah number β. The sway of λ_1 is to rise the heat limiting viscosity.

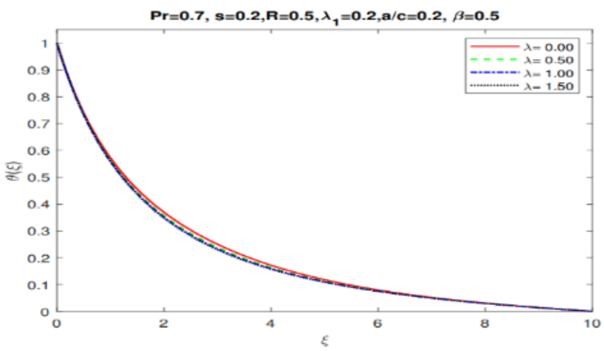


fig (4)

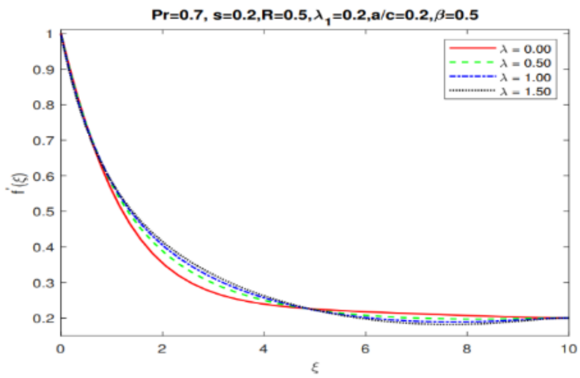
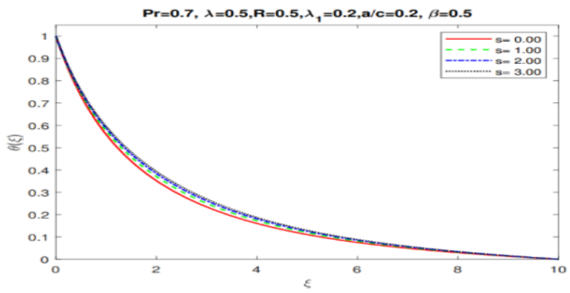
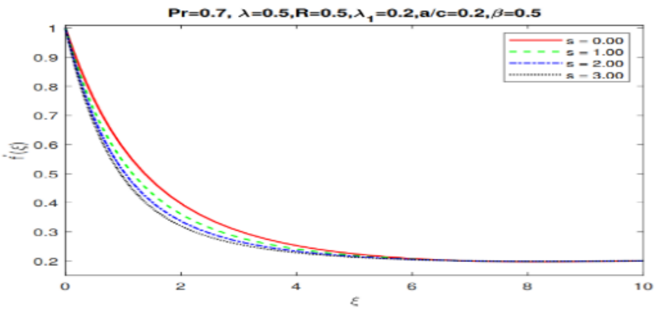


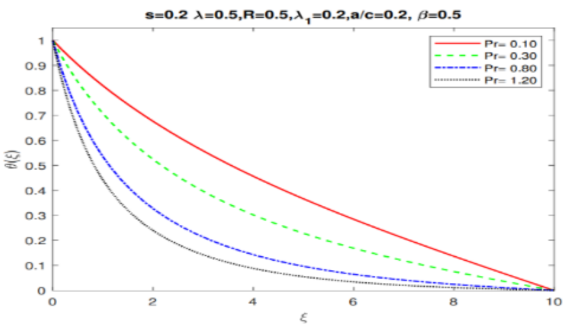
fig (5)



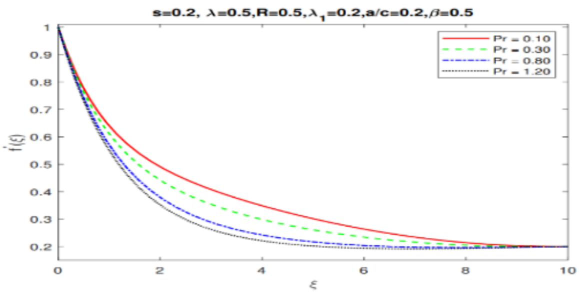
fig(6)



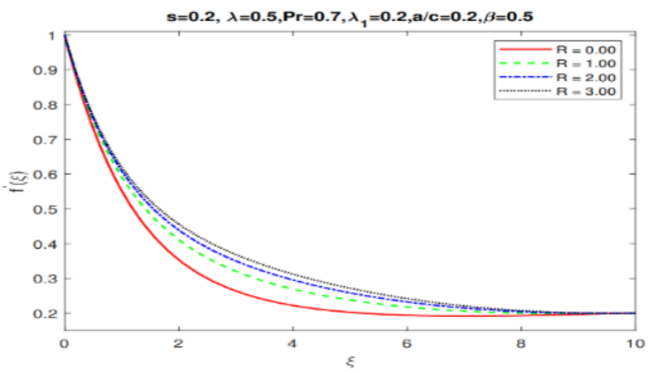
fig(7)



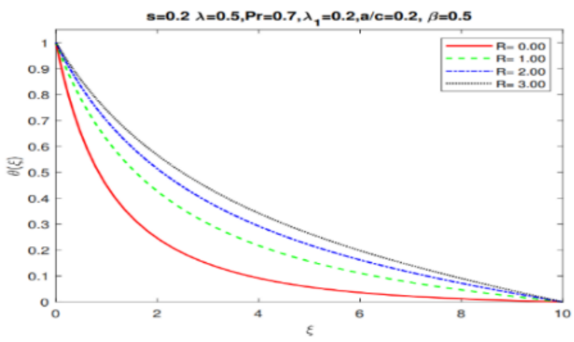
fig(8)



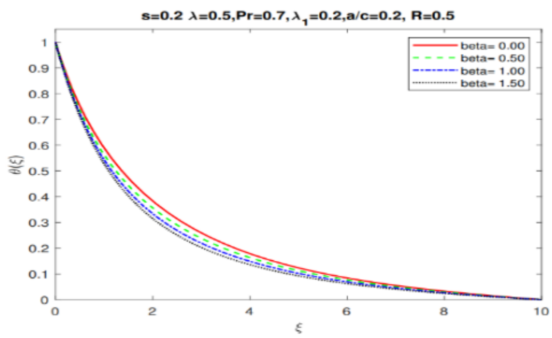
fig(9)



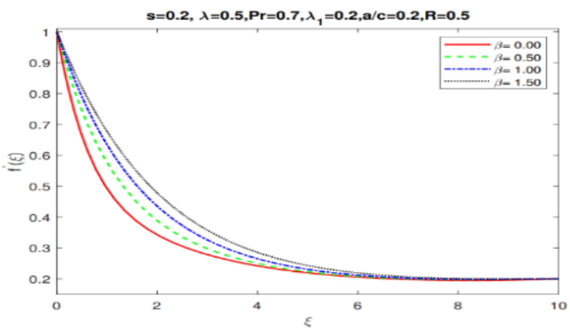
fig(10)



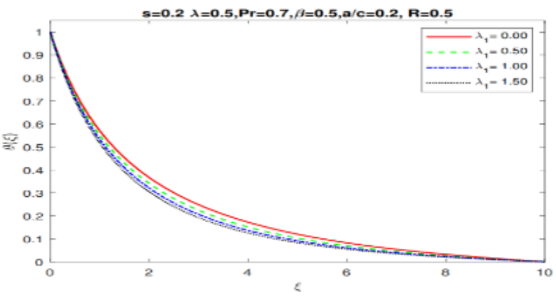
fig(11)



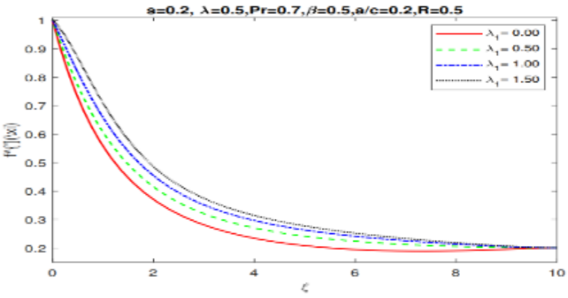
fig(12)



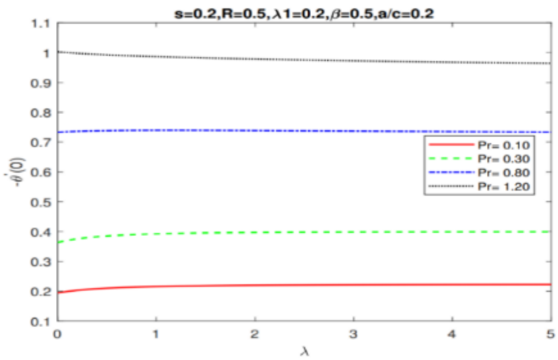
fig(13)



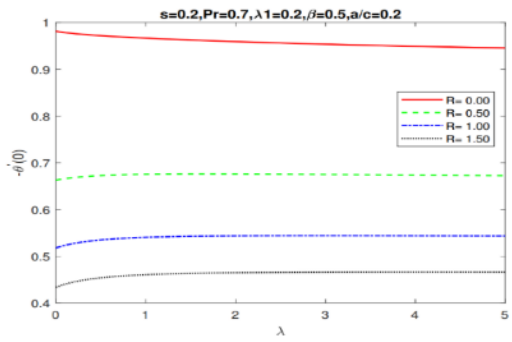
fig(14)



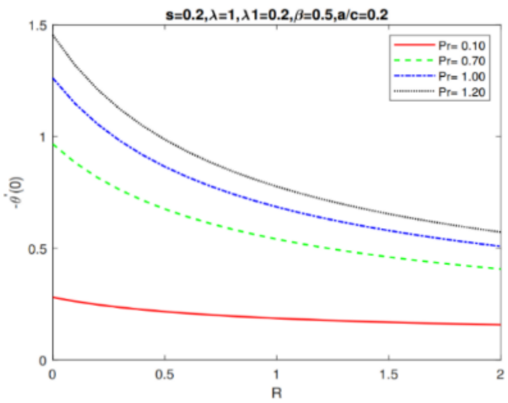
fig(15)



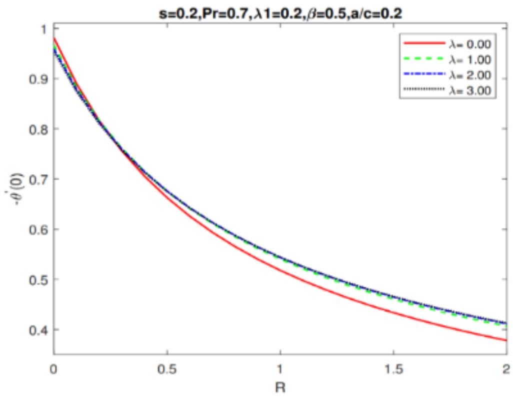
fig(16)



fig(17)



fig(18)



fig(19)

fig (16) shows the transformation of the local Nusselt number $-\theta'(0)$ with λ for various values of Pr and R, respectively. It is noticeable from fig (17) that both the Prandtl number Pr and the mixed convection parameter λ show similar outcomes on the local Nusselt number, i.e increasing Pr and λ decreases the rate of $-\theta'(0)$.

Table 1. Study of values of f''(0) for contrasting values of a/c when Pr = 1, λ = 0, and S = 0

a/c	Present	[18]	[19]
0.01	-0.99294531	-0.9980	-0.99823
0.10	-0.96722118	-0.9694	-0.96954

0.20	-0.91735876	-0.9181	-0.91813
0.50	-0.66724192	-0.6673	-0.66735
2.00	2.01750280	2.0175	2.01767
3.00	4.72928235	4.7294	4.72964
10.00	36.25744237	36.2603	36.24021

Table 2. Comparison of values of −θ '(0) when a/c = 0 and λ = 0.

s	Pr=0.72			Pr=1			Pr=10		
	Present	[18]	[19]	Present	[18]	[19]	Present	[18]	[19]
-1.00	0.97939359	0.5455	0.54547	1.27550244	0.6181	0.61805	10.36671961	0.9418	0.94167
-0.60	0.92496037	0.6345	0.36462	1.20836787	0.7441	0.74423	10.24763569	1.4709	1.47088
-0.40	0.89443712	0.6866	0.68657	1.16986626	0.8198	0.81944	10.17498051	1.9681	1.96832
-0.20	0.86205625	0.7446	0.74459	1.12836932	0.9050	0.90534	10.09220519	2.7096	2.70945
0.00	0.82826044	0.8088	0.80873	1.08436672	1.0000	1.00000	9.99829893	3.7208	3.72068
0.20	0.79362185	0.8798	0.87975	1.03856396	1.1050	1.10524	9.89229285	4.9765	4.97643
0.40	0.75879617	0.9575	0.95748	0.99183429	1.2198	1.21974	9.77325560	6.4260	6.42598
0.60	0.72445401	1.0420	1.04293	0.94512911	1.3440	1.34434	9.64026646	8.0178	8.01778
1.00	0.65954279	1.2297	1.22965	0.85533181	1.6180	1.61823	9.32866209	11.4762	11.4347

Table 3. study of values of f ''(0) for contrasting values of a/c when Pr = 1, λ = 0, and S = 0.

a/c	$\lambda = -0.1$			$\lambda = 1.0$		
	Present	[18]	[19]	Present	[18]	[19]
0.00	-1.00637116	-1.0513	-1.0513	-0.98269961	-0.5608	-0.56076
0.01	-1.00531008	-1.0490	-1.0490	-0.98069415	-0.5596	-0.55923
0.05	-0.99886565	-1.0372	-1.0372	-0.96931744	-0.5528	-0.55345
0.10	-0.98622938	-1.0176	-1.0176	-0.94827103	-0.5398	-0.53982
0.20	-0.94756576	-0.9638	-0.9638	-0.88708308	-0.5002	-0.50023
0.50	-0.74537437	-0.7075	-0.7075	-0.58871558	-0.2846	-0.28446
1.00	-0.18624752	-0.0343	-0.0343	0.18798721	0.3350	0.33501
2.00	1.54961846	1.9899	1.9899	2.49562473	2.2913	2.29156

Table 4. Comparison of values of $-\theta'(0)$ for contrasting values of a/c when Pr = 1, λ = 0, and S = 0.

	$\lambda = -0.1$					$\lambda = 1.0$
a/c	Present	[18]	[19]	Present	[18]	[19]
0.00	1.09012550	0.9856	0.98545	1.07834048	1.0873	1.08756
0.01	1.09421939	0.9880	0.98834	1.08342710	1.0881	1.08782
0.05	1.11135377	0.9977	0.99725	1.10497511	1.0921	1.09543
0.10	1.13406776	1.0079	1.00737	1.13383714	1.0982	1.09567
0.20	1.18197354	1.0362	1.03623	1.19464449	1.1133	1.15642
0.50	1.33046143	1.1186	1.11898	1.37836348	1.1714	1.17647
1.00	1.57139693	1.2502	1.25127	1.66633403	1.2827	1.28565
2.00	2.02093666	1.4855	1.48523	2.19128916	1.5020	1.51136

Table 5 Values of the surface heat transfer −θ’ (0) when Pr = 0.7 and NR = 0.3.

a/c	beta	Lambda	Lambda1	$-\theta'(0)$
0.00	0.1	0.5	0.2	0.70818925
0.05				0.71473048
0.12				0.72595617
0.30				0.76352484
0.2	0.00			0.72989898
	0.20			0.75170821
	0.30			0.76123228
	0.40			0.77000275
0.2	0.1	0.00		0.72498732
		0.30		0.73692400
		0.70		0.74423450
		1.00		0.74699132
0.2	0.1	0.5	0.00	0.72659511
			0.10	0.73400160
			0.30	0.74853446
			0.50	0.76270508

A comparative study of numerical values is done with the present and previously done by [18] A. Ishak, R. Nazar, N. Bachok has done investigation of MHD mixed convection flow on a vertical permeable surface close to the stagnation point and [19] Tasawar Hayata, Sabir Ali Shehzada , Muhammad Qasima, et al has studied of Effects of Thermal Radiation on Mixed Convection Stagnation-Point Flow in a Jeffery Fluid using the homotopy analysis method (HAM).the final conclusion is the outcome of combined convection parameter λ, stretching ratio a/c, on the velocity profile $\mathbf{f'}$ are similar in a qualitative sense.

conflict of interest: Not applicable

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Nomenclature

a/c stretching ratio
λ combined convection parameter
c_p specific heat at constant pressure
D diffusion coefficient[m^2/s]
E extra stress tensor
R radiation parameter
R_1 Rivlin-Erickse tensor
$U_w$shrinking velocity [m/s]
u, v velocity components in the x,y directions,resp.[m/s]
$\lambda_1$ratio of relaxation and retardation time
λ_2 relaxation time
τ Cauchy stress tensor
υ kinematic viscosity [m^2/s]
ρ fluid density [Kg/m]
T fluid temperature
T_∞temperature far away from the wall[K]
K fluid thermal conductivity [W/m/K]
K_s Rosseland mean absorption coefficient
Kr^* chemical reaction parameter
σ^* Stefan-Boltzmann constant
θ non dimensional temperature
q_r radiative heat flux
Pr Prandtl number
β Deborah number
Sc Schmidt number
γ_T Thermal expansion coefficient
x distance along the wall[m]
y distance normal to the wall [m]
ξ similarity variable
l characteristic length

Subscripts

w sheet surface
∞ infinity

Superscript

$'$ differentiation with respect to ξ