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ENERGY SOURCE IMPACTS ON STEADY CHEMICALLY RADIATIVE JEFFREY LIQUID OVER A SHEET

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ABSTRACT. This study is the collective impact of energy and momentum transport in Jeffrey fluid over a stretching sheet in the occurrence of energy source/ sink, thermal radiation and chemical reaction. The surface thermal and the dilution are implicit to vary according to power law form. The foremost PDE equations of our replica are renovated into ODEs by employing similarity variables and then sketched out via HAM technique. Impact of embedding motion factors on motion thermal and momentum have been framed in the brightness of parametric study. The influences of different pertinent parameters are explained through graphs and tables. Favorable comparison with existing literatures has been revealed and it depicts tremendous similarity. It is observed that the flow increases with an increase in Deborah number. Further the thermal is a blow down function of Deborah number. Thermal border layer thickness increases by rising the wall thermal and energy source parameters.

1. INTRODUCTION

The attention in energy transport problem connecting non-Newtonian liquids has grown considerably as the application of non-Newtonian liquids.Typical non- Newtonian flow characteristic include shear-thinning, shear thickness, visco-elasticity, visco-elasticity and so forth. In view of this a lot of interest has been

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shown towards the study of non-Newtonian flows and hence extensive literature regarding analytical and numerical solution is available on the topic [1-12].

Exact solutions further narrow down when non-Newtonian liquids are taken into account [13-14]. Hayat et al. [15] proposed the impacts of Newtonian energying magnetohydrodynamics (MHD) in a motion of a Jeffrey liquid over a radially stretching surface. In the same year, Hayat et al. [16] carried out the study of border layer stretched motion of a Jeffrey liquid subject to the convective border settings. Shehzad et al. [17] analytically discussed magnetohydrodynamics (MHD) three-dimensional motion of Jeffrey liquid in the presence of Newtonian energying. Farooq et al. [18] examined the mutual impacts of Joule and Newtonian energying in magnetohydrodynamic (MHD) motion of Jeffrey liquid over a stretching cylinder with energy source/sink solved analytically by homotopy analysis technique (HAM).

The transport of energy is important because the rate of cooling can be restricted and final products of desired characteristics might be achieved. The flow on a flat plate with regular free stream has been examined by Basius [19].

Hayat and Mustafa [20] explained the impact of the thermal radiation on the unsteady mixed convection motion of Jeffrey liquid past a porous vertical stretching surface analytically using homotopy analysis technique. Hayat et al. [21] extended the previous idea to examine the motion of an incompressible Jeffrey liquid over a stretching surface in the presence of power energy flux and energy source. Shehzad et al. [22] derived homotropy solutions for magnetohydrodynamic radiative motion of an incompressible Jeffrey liquid over a linearly stretched surface. In another study, Shehzad et al. [23] proposed the 3D hydromagnetic motion of Jeffrey liquid with nanoparticles where the impacts of thermal radiation and internal energy generation are considered. Hussain et al. [24] analyzed energy and momentum transport analysis of two dimensional hydromagnetic motion of an incompressible Jeffrey nanoliquid over an exponentially stretching surface in the presence of thermal radiation, viscous dissipation, Brownian motion, and thermophoresis impacts. Very recently, the influence of melting energy transport and thermal radiation on MHD stagnation point motion of an electrically conducting Jeffrey liquid over a stretching sheet with partial surface slip has been conducted numerically by Das et al. [25] with the assist of RungeKutta-Fehlberg technique.

Here our main focus is to discuss the influence of thermal radiation on steady convection motion of Jeffrey liquid over a stretching sheet with energy source/sink. The HAM technique is applied in this study in order to find the numerical solutions for flow, thermal and dilution profiles. Terminology of skin friction, Nusselt number and Sherwood number are also given. Graphical results are provided and discussed for embedded parameters.

2. Mathematical Formulation

We consider a steady two-dimensional laminar radiative motion of an incompressible Jeffrey liquid over a stretching surface. Here the impact of chemical reaction is taken into account. A Cartesian coordinate system is chosen in such a way that x-axis is along the stretching surface and the y-axis perpendicular to it. The motion configuration and coordinate system are as shown in Figure 1.

The constitutive equations for Jeffrey liquid can be written as $\tau = -pI + S$, With S as the extra stress tensor and it defined by

$$S = \frac{\mu}{1+\lambda}\left[R_1 + \lambda_1\left(\frac{\partial R_1}{\partial t} + V \bullet \nabla\right) R_1\right],$$

where τ is the Cauchy stress tensor μ ,is the dynamic viscosity λ_1, λ_2 and are the material parameters of Jeffrey liquid and R_1 is the Rivlin-Ericksen tensor defined by $R_1 = (\nabla V) + (\nabla V)'$.

Under the border layer approximations, the governing equations for conservation of momentum, momentum, thermal energy and nanoparticle dilution of this problem can be expressed as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{2.1}$$

(2.2)
$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y} = \frac{v}{1+\lambda}\left\{\frac{\partial^2 u}{\partial y^2}+\lambda_1\{u\frac{\partial^3 u}{\partial x\partial y^2}+v\frac{\partial^3 u}{\partial y^3}-\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial y^2}+\frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial x\partial y}\}\right\}$$
(2.3)
$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho c_p}\frac{\partial qr}{\partial y}+\frac{1}{\rho c_p}Q_0(T_\infty-T)$$
(2.4)
$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2}-k_0(C-C_\infty)\,.$$
Subject to the border settings

$$u=U_w(x)=cx, v=0, T=T_w=T_\infty+A_1\left(\frac{x}{l}\right)^n, \tag{2.5}$$
$$C = C_w=C_\infty+A_2\left(\frac{x}{l}\right)^n \text{ at } y=0, u\to 0, T\to T_\infty, C\to C_\infty \text{ as } y\to\infty\,,$$

where and are the flow components in and directions, is the kinematic viscosity, is the liquid density, is the ratio of relaxation and retardation times, is the relaxation time, is the electrical conductivity of the liquid, is the coefficient of viscosity, is the specific energy at constant pressure, is the thermal in the border layer, is the dilution of the liquid, is the thermal conductivity, is the energy source coefficient, is the radiative energy flux, is the free stream thermal, is the free stream dilution , is the proportionality constant, is the diffusion coefficient, is the chemical reaction rate, are the constants depending upon the properties of the liquid, is the characteristic length.

Now, we introduce the following similarity transformations:
$$u=Cxf^1(\varsigma)=\varsigma=y\sqrt{\frac{c}{v}}=v=-\sqrt{cv}f(\varsigma),\theta(\varsigma)=\frac{T-T_\infty}{T_w-T_\infty},\phi(\varsigma)=\frac{C-C_\infty}{C_w-C_\infty}\,.$$
Equation (2.1) is automatically satisfied and the equations (2.2) to (2.5) can be written as:

$$f'''+\beta\left(f''^2-ff'''\right)+(1+\lambda)\left(ff''-f'^2\right)=0 \tag{2.6}$$

$$\left(1+\frac{4}{3}R\right)\theta''+\Pr f\theta'-n\Pr f'\theta+\Pr Q\theta=0 \tag{2.7}$$

$$\phi''+Scf\phi'-nScf'\phi-ScK\phi=0 \tag{2.8}$$

The border settings are

$$f\,(0)=0, f'(0)=1, \theta(0)=1, \phi(0)=1 f'\,(\infty)=0, \theta(\infty)=0, \phi(\infty)=0\,, \tag{2.9}$$

where prime denotes differentiation with respect to

$$\zeta, \beta=\lambda_1 c$$

is the Deborah number,

$$\mathrm{Pr}=\frac{\rho C_p v}{k}$$

is the Prandtl number,

$$R=\frac{4\sigma^* T_\infty^3}{k k^*}$$

is the radiation parameter,

$$Q=\frac{Q_0}{\rho C_p c}$$

$$\mathcal{K}=\frac{k_0}{c}$$

is the energy generation parameter, is the chemical reaction parameter,

$$Sc=\frac{v}{D_B}$$

is the Schmidt number.

Here, we depict the steps to acquire the solutions of the Equations (2.6) to (2.8) subjected to the border settings (2.9) using HAM. For this intent, we take the initial guesses f_0,θ_0 and ϕ_0 of f,θ and ϕ in the following form

$$f_0(\zeta)=1-e^{-\zeta}, \theta_0(\zeta)=e^{-\zeta}, \phi_0(\zeta)=e^{-\zeta}.$$

The linear operators are selected as

$$L_1\,(f)=f'''-f', L_2\,(\theta)=\theta''-\theta, L_3\,(\phi)=\phi''-\phi$$

with the following properties

$$L_1\left(C_1+C_2 e^{\zeta}+C_3 e^{-\zeta}\right)=0$$

$$L_2\left(C_4 e^{\zeta}+C_5 e^{-\zeta}\right)=0$$

$$L_3\left(C_6 e^{\zeta}+C_7 e^{-\zeta}\right)=0$$

where $C_i(i = 1\ to\ 7)$ are the arbitrary constants. We construct the zeroth-order deformation equations as

$$
\begin{aligned}
&(1-p)L_1\left(f\left(\zeta;p\right)-f_0(\zeta)\right)=pN_1\left[f\left(\zeta;p\right)\right]\\
&(1-p)L_2\left(\theta\left(\zeta;p\right)-\theta_0(\zeta)\right)=pN_2\left[f\left(\zeta;p\right);\theta\left(\zeta;p\right)\right]\\
&(1-p)L_3\left(\phi\left(\zeta;p\right)-\phi_0(\zeta)\right)=pN_3\left[f\left(\zeta;p\right);\phi\left(\zeta;p\right)\right]\ ,
\end{aligned}
$$

subject to the border settings

$$f(0;p)=0, f'(0;p)=1, f'(\infty;p)=0, \theta(0;p)=1, \theta(\infty;p)=1, \theta'(0;p)=1, \phi(\infty;p)=0$$

$$
\begin{aligned}
N_1\left[f\left(\zeta;p\right)\right] &= \frac{\partial^3 f\left(\zeta;p\right)}{\partial\zeta^3}+\beta\left(\left(\frac{\partial^2 f\left(\zeta;p\right)}{\partial\zeta^2}\right)-f\left(\zeta;p\right)\frac{\partial^4 f\left(\zeta;p\right)}{\partial\zeta^4}\right)\\
&\quad +(1+\lambda)\left(f\left(\zeta;p\right)\frac{\partial^2 f(\zeta;p)}{\partial\zeta^2}-\left(\frac{\partial f(\zeta;p)}{\partial\zeta}\right)^2\right)\\
N_2\left[f\left(\zeta;p\right),\theta(\zeta;p)\right] &= \left(1+\frac{4}{3}R\right)\frac{\partial^2\theta(\zeta;p)}{\partial\zeta^2}+\Pr\left(f(\zeta;p)\frac{\partial\theta(\zeta;p)}{\partial\zeta}-n\frac{\partial f(\zeta;p)}{\partial\zeta}\theta(\zeta;p)\right)\\
&\quad +\Pr Q\theta(\zeta;p)\\
N_3\left[f\left(\zeta;p\right),\theta(\zeta;p)\right] &= \frac{\partial^2\phi(\zeta;p)}{\partial\zeta^2}+Sc\left(f(\zeta;p)\frac{\partial\phi(\zeta;p)}{\partial\zeta}-n\frac{\partial\phi(\zeta;p)}{\partial\zeta}\phi(\zeta;p)-K\phi(\zeta;p)\right)\ ,
\end{aligned}
$$

where $p\in[0,1]$ is the embedding parameter. When $p=0$ and $p=1$, we obtain

$$
\begin{aligned}
&f\left(\zeta;0\right)=f_0\left(\zeta\right), f\left(\zeta;1\right)=f\left(\zeta\right), \theta\left(\zeta;0\right)=\theta_0\left(\zeta\right), \theta\left(\zeta;1\right)=\theta\left(\zeta\right),\\
&\qquad\qquad \phi\left(\zeta;0\right)=\phi_0\left(\zeta\right), \phi\left(\zeta;1\right)=\phi\left(\zeta\right)\ .
\end{aligned} \tag{2.10}
$$

Thus, as p increases from 0 to 1 then $f(\zeta;p)$,$\theta(\zeta;p)$ and $\phi(\zeta;p)$ vary from initial approximations to the exact solutions of the original nonlinear differential equations.

Now, with the help of Taylor's series, we can write

$$f\left(\zeta;p\right) = f_0\left(\zeta\right)+\sum_{m=1}^{\infty}f_m\left(\zeta\right)p^m \tag{2.11}$$

$$\theta\left(\zeta;p\right) = \theta_0\left(\zeta\right)+\sum_{m=1}^{\infty}\theta_m\left(\zeta\right)p^m \tag{2.12}$$

$$\phi\left(\zeta;p\right) = \phi_0\left(\zeta\right)+\sum_{m=1}^{\infty}\phi_m\left(\zeta\right)p^m. \tag{2.13}$$

where

$$f_m(\zeta) = \left(\frac{1}{m!}\frac{\partial^m f(\zeta;p)}{\partial p^m}\right)_{p=0} \theta_m(\zeta) = \left(\frac{1}{m!}\frac{\partial^m \theta(\zeta;p)}{\partial p^m}\right)_{p=0} \phi_m(\zeta) = \left(\frac{1}{m!}\frac{\partial^m \phi(\zeta;p)}{\partial p^m}\right)_{p=0}.$$

If the initial approximations, auxiliary linear operators and non-zero auxiliary parameters are chosen in such a way that the series (2.11) to (2.13) are convergent at p=1, then

$$\begin{aligned} f(\zeta) &= f_0(\zeta) + \sum_{m=1}^{\infty} f_m(\zeta) \\ \theta(\zeta) &= \theta_0(\zeta) + \sum_{m=1}^{\infty} \theta_m(\zeta) \\ \phi(\zeta) &= \phi_0(\zeta) + \sum_{m=1}^{\infty} \phi_m(\zeta). \end{aligned}$$

The mth-order deformation equations are follows

$$\begin{aligned} L_1(f_m(\zeta) - \mathrm{X}_m f_{m-1}(\zeta)) &= \mathrm{R}_{\mathrm{m}}^{\mathrm{f}}(\zeta) \\ L_2(\theta_m(\zeta) - \mathrm{X}_m \theta_{m-1}(\zeta)) &= \mathrm{R}_{\mathrm{m}}^{\theta}(\zeta) \\ L_3(\phi_m(\zeta) - \mathrm{X}_m \phi_{m-1}(\zeta)) &= \mathrm{R}_{\mathrm{m}}^{\phi}(\zeta), \end{aligned}$$

with the following border settings

$$\begin{gathered} f_m(0) = 0, f_m(0) = 0, f_m(\infty) = 0, \theta_m(0) = 0, \\ \theta_m(0) = 0, \theta_m(\infty) = 0, \phi_m(0) = 0, \phi_m(0) = 0, \phi_m(\infty) = 0 \end{gathered}$$

where

$$\begin{aligned} R_m^f(\zeta) &= f_{m-1}''' + \beta\left(\sum_{i=0}^{m-1} f_{m-1-i}'' f_i'' - \sum_{i}^{m-1} f_{m-1-i} f_i'''\right) + \\ &\quad (1+\lambda)\left(\sum_{i=0}^{m-1} f_{m-1-i} f_1'' - \sum_{i=0}^{m-1} f_{m-1-i}' f_i'\right) \\ R_m^\theta(\zeta) &= \left(1 + \frac{4}{3}\right)\theta_{m-1}'' + \Pr\left(\sum_{i=0}^{m-1} f_{m-1-i}\theta_i - n\sum_{i=0}^{m-1} f_{m-1-i}'\theta_i\right) + \Pr Q\theta_{m-1} \\ R_m^\phi(\zeta) &= \phi_{m-1}'' + Sc\left(\sum_{i=0}^{m-1} f_{m-1-i}\phi_i' - n\sum_{i=0}^{m-1} f_{m-1-i}'\phi_i - K\phi_{m-1}\right) \end{aligned}$$

$$\chi_m = \left\{ \begin{array}{ll} 0, & m \leq 1, \\ 1\,, & m > 1 \end{array} \right\}.$$

3. Convergence of HAM solution

The higher deformation equations corresponding to Equations (2.6) to (2.8) subject to the border settings (2.9) can be formulated using above initial guesses and linear operators (and the appropriate ideals for the non-zero parameters $\hbar_1$,$\hbar_2$ and θ_3 have been obtained by plotting the $\hbar$ -curves in Figure 1. From the figure, it is seen that the valid regions of $\hbar_1$,$\hbar_2$ and θ_3 are about [-1.0, 0.0]. For $\hbar_1 = \hbar_2 = \theta_3$ our results are in good correlation with the existing results. Table 1 displays the convergence of adopted technique. Table 1. Convergence of HAM solution for different orders of approximations when $\beta = 1.0$,$\lambda = 0.2$,$R = 0.1$,Pr=0.7,n=2.0,Q=0.1,Sc=0.7,K=0.1.

TABLE 1

order	$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$
5	- 0.772456	- 1.4013272	- 0.944135
10	- 0.774636	- 1.012193	- 0.945268
15	- 0.774597	- 1.012486	- 0.945303
20	- 0.774596	- 1.012467	- 0.945301
25	- 0.774596	- 1.012463	- 0.945301
30	- 0.774596	- 1.012461	- 0.945301
35	- 0.774596	- 1.012461	- 0.945301
40	- 0.774596	- 1.012461	- 0.945301

4. figures

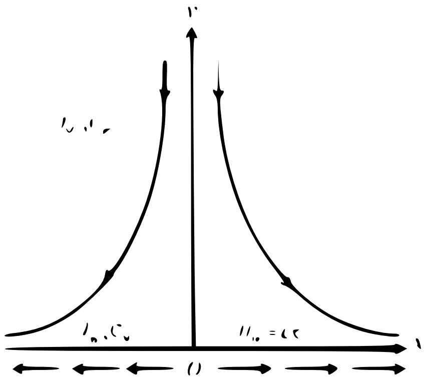

Figure 1 Physical model and coordinate system

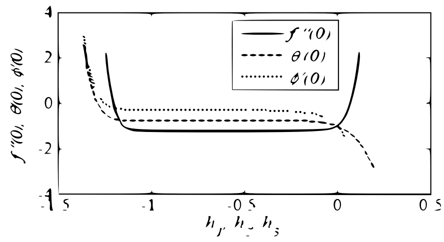

Fig 2 η-curves of $f''(0)$, $\theta'(0)$ and $\phi'(0)$ for 15th order approximation

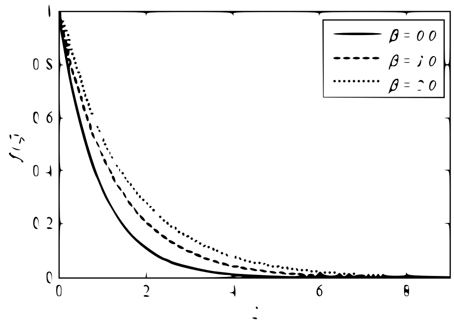

Fig 3 Impact of β on $f'(\zeta)$

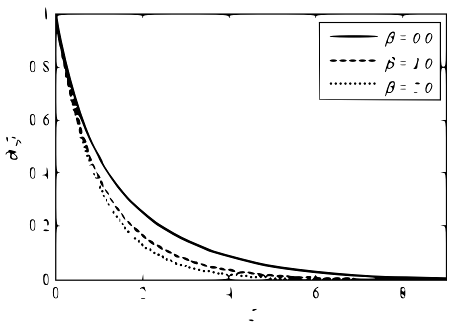

Fig 4 Impact of β on $\theta(\zeta)$

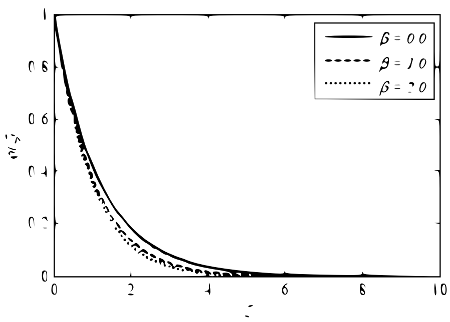

Fig 5 Impact of β on $\phi(\zeta)$

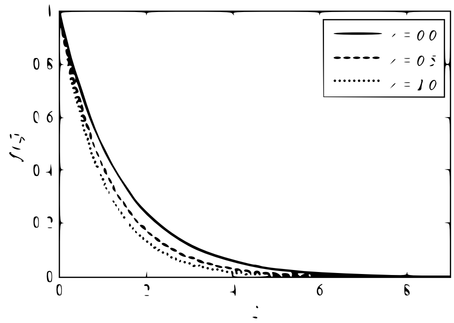

Fig 6 Impact of λ on $f'(\zeta)$

5. Results and Discussion

The aspiration of this revise is to interpret the outcomes of a variety of parameters such as Deborah numberβ, surface thermal parameter (m), ratio of relaxation and retardation times(λ) , surface thermal parameter(n) , radiation parameter(R) , Prandtl number(Pr) , energy source parameter(Q) , Schmidt

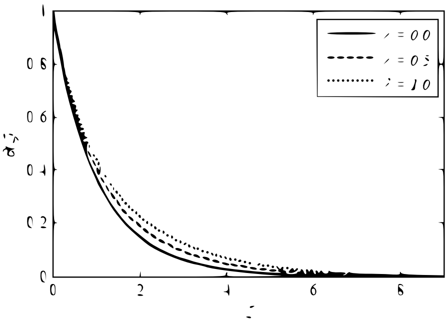

Fig 7 Impact of λ on $\theta(\zeta)$

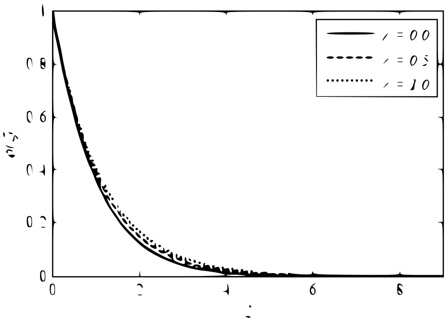

Fig 8 Impact of λ on $\phi(\zeta)$

number(Sc) and chemical reaction parameter(K) on flow, thermal, skin friction coefficient and Nusselt number. In this study the default parameter ideals are undertaken for computations: $\beta = 1.0$,$\lambda = 0.2$,$R = 0.1$,$Pr = 0.7$,$Q = 0.1$,$n = 2.0$,$Sc = 0.7$,$k = 0.1$

In order to validate the numerical technique used in this study, a comparison is made with the earlier works of Adamu Gizachew and Bandari Shankar shown in Table 1. The results are found in excellent agreement.

Figures 3-8 are plotted to study dimensionless flow, thermal, dilution distribution, local friction, local Nusselt and local Sherwood numer for various impacts of governing parameters. It is observed from Figures 3-5 display the characteristics of the Deborah number(β) parameter on the motion of the liquid, thermal border and dilution distributions. It is noticed that liquid flow enhances with increase in(β), while the reverse tend for thermal and dilution of the liquid. The manipulate of ratio of relaxation and retardation times(λ) , on flow, thermal and dilution profile is pointed in Figures. 6-8. It is pragmatic that liquid flow is lower for higher ideals of(λ). An opposite tendency is noticed for the variation of(λ)on thermal and dilution of the liquid.

6. CONCLUSIONS

In this manuscript the impact of thermal radiation, chemical reaction and energy source on steady convection of a Jeffrey fluid past over a stretching sheet are studied. The basic equation of continuity, momentum, energy and dilution are modelled and transformed using similarity transformation and then solved by Homotopy Asymptotic Technique (HAM). The converted equations are also solved by numerical technique. A systematic study on the impacts of non-Newtonian and other physical parameters controlling the motions, energy and momentum transport description is approved out. From the calculated results the following final remarks can be drawn:

(1) It was traditional that the Prandtl number blow down the thermal border layer thickness which helps in maintaining system thermal of the fluid flow.
(2) It is noticed that the thermal distribution is superior for energy source parameter.
(3) From this simulation it is noticed that an enhancement in the Schmidt number or chemical reaction parameter blow downs the dilution border layer thickness.
(4) It is found that the non-Newtonian parameter leads to an increase in the border layer thickness as results the liquid motion become complicated as compared to the Newtonian liquid which has the constant viscosity. Since the liquid is highly viscous so the flow is additional for non-Newtonian liquid as compared with Newtonian due to many parameters coming into the replica.

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