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Effect of Temperature Dependent Viscosity on the Peristaltic Transport of Jeffrey Fluid

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ABSTRACT

This paper deals with an investigation on the peristaltic flow of a Jeffrey fluid with temperature dependent viscosity. The governing equations of nonlinear partial differential equations are simplified under the long wavelength and low Reynolds number approximations. The reduced governing equations are solved by using perturbation method. The expressions for the stream function, pressure gradient , velocity and temperature are obtained. The physical features of pertinent parameters have been discussed by plotting the graphs of velocity, pressure rise, temperature, pressure gradient, heat transfer coefficient and the friction force. It is noticed that the velocity and temperature decrease with increasing the the ratio of relaxation to retardation times (λ_1).

Keywords:Temperature,Viscosity,Peristaltic transport, Jeffrey fluid.

1. INTRODUCTION

Peristalsis is an highly important mechanism in modern physiological world, applied mathematics and several engineering. Peristalsis has many applications in real life such as swallowing food through the esophagus, chime motion in the gastrointestinal tract, in the vaso-motion of small blood vessels such as veins, capillaries, and ductus efferentus of the reproductive tract, arterioles, urine transport from kidney to bladder, in sanitary fluid transport, transport of slurries, corrosive fluids, a toxic liquid transport in the nuclear industry, etc.

Moreover, the study of peristalsis has a key role in designing the roller pumps, finger pumps, dialysis machines, heart lung machines and blood pump machines. In the light of physiological and industrial applications, the mechanism of peristalsis has received special attention of the modern researchers. In fact Latham [1966] was the first researcher who investigated the mechanism of peristalsis experimentally. Soon after, Burns et al. [1967] and Shapiro *et al.* [1969] have focused their attention to the study of peristaltic flows. Burns et al. discussed the peristaltic motion by considering the sinusoidal type wall deformations while Shapiro *et al.* analyzed the peristaltic pumping in the presence of long wavelength and low Reynolds number assumptions.

Many researchers have discussed the peristaltic flows of viscous and non-Newtonian fluids theoretically and experimentally . A variety of non-Newtonian fluids have been proposed in literature describing several rheological features. One of the sub class of non-Newtonian fluids known as Jeffrey fluid which has been attracted the attention of various researchers due to its simplicity. Jeffrey fluid model describes the characteristics of relaxation and retardation times.

Ali *et al.* [2010] studied the heat transfer analysis of peristaltic flow of viscous fluid in a curved channel.Vajravelu *et al.* [2011] discussed the effects of heat transfer on peristaltic transport of a Jeffrey fluid in a vertical porous stratum. Tripathi [2012] presented a mathematical model for swallowing of food bolus through the oesophagus when heat effects are present. Further, the readers may be mentioned to the interesting studies on the interaction of heat transfer with peristalsis.

Ravi Kumar *et al.* [2014] considering Jeffrey fluid in their studies on peristaltic pumping. Ravi Kumar *et al.* [2010] studied peristaltic pumping in a finite length tube .In their study they considered different flow geometrics by taking various non-Newtonian flow models .

In spite of all the previous studies, the aim of present study is to develop a mathematical model addressing the peristaltic flow of a Jeffrey fluid by considering temperature dependent viscosity. To our knowledge such analysis has not been reported so far. This study is organized as follows. The solutions of the governing non-linear analysis are obtained in section three. In section four, the graphical results are presented and discussed with respect to the involved parameters. Section five is devoted to the concluding remarks.

2. MATHEMATICAL FORMULATION

Consider the two-dimensional flow of an incompressible Jeffrey fluid reactive variable viscosity fluid in a symmetric channel of uniform thickness 2d. Temperature of the channel walls is T_W. The viscosity of the fluid is assumed temperature dependent. The flow is driven by propagation of the sinusoidal wave trains along the channel walls with constant speed. Flow configuration in the present consideration is shown in Fig. 1. The wall deformation in rectangular coordinate system $(\bar{X}, \bar{Y}, \bar{t})$ is defined by

$$\bar{H}(\bar{X}, \bar{t}) = d + b\cos\left[\frac{2\pi}{\lambda}\left(\bar{X} - c\bar{t}\right)\right] \tag{1}$$

Where d represents the channel half width, b represents the wave amplitude, λ represents the wavelength, $\bar{X}$ represents the direction of the wave propagation and $\bar{t}$ represents the time. The unsteady flow can be treated as steady by switching from fixed frame $(\bar{X},\bar{Y})$ to $(\bar{x},\bar{y})$ wave frame which travels in $-\bar{X}$ direction with the wave speed c. For this purpose the transformation between the two frames are given as follows:

$$(\bar{x},\bar{y})=\left(\bar{X}-c\bar{t},\bar{Y}\right),\quad (\bar{u},\bar{v})=\left(\bar{U}-c,\bar{V}\right),\ \bar{p}(\bar{x})=\bar{P}\left(\bar{X},\bar{t}\right) \tag{2}$$

in which $\bar{U},\bar{V}$ are the velocity components in the fixed frame and $\bar{u},\bar{v}$ are the velocity components in wave frame. Further $\bar{p}$ is the pressure in the fixed frame and $\bar{P}$ is the pressure in wave frame.

In wave frame, the equations of continuity, momentum and energy in the absence of reactant fluid consumption are given

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

$$\rho\left(\bar{u}\frac{\partial\bar{u}}{\partial\bar{x}}+\bar{v}\frac{\partial\bar{u}}{\partial\bar{y}}\right)=-\frac{\partial\bar{p}}{\partial\bar{x}}+2\frac{\partial}{\partial\bar{x}}\left(\frac{\bar{\mu}}{1+\lambda_1}\frac{\partial\bar{u}}{\partial\bar{x}}\right)+\frac{\partial}{\partial\bar{y}}\left[\frac{\bar{\mu}}{1+\lambda_1}\left(\frac{\partial\bar{v}}{\partial\bar{x}}+\frac{\partial\bar{u}}{\partial\bar{y}}\right)\right] \tag{4}$$

$$\rho\left(\bar{u}\frac{\partial\bar{v}}{\partial\bar{x}}+\bar{v}\frac{\partial\bar{v}}{\partial\bar{y}}\right)=-\frac{\partial\bar{p}}{\partial\bar{x}}+2\frac{\partial}{\partial\bar{y}}\left(\frac{\bar{\mu}}{1+\lambda_1}\frac{\partial\bar{v}}{\partial\bar{x}}\right)+\frac{\partial}{\partial\bar{x}}\left[\frac{\bar{\mu}}{1+\lambda_1}\left(\frac{\partial\bar{v}}{\partial\bar{x}}+\frac{\partial\bar{u}}{\partial\bar{y}}\right)\right] \tag{5}$$

$$\rho\left(\bar{u}\frac{\partial\bar{T}}{\partial\bar{x}}+\bar{v}\frac{\partial\bar{T}}{\partial\bar{y}}\right)=k\left(\frac{\partial^2\bar{T}}{\partial\bar{x}^2}+\frac{\partial^2\bar{T}}{\partial\bar{y}^2}\right)+SC_0Ae^{\frac{-E}{R\bar{T}}} \tag{6}$$

In above equations $\rho,\bar{T},c_p,k,S,C_0,E,R$ and A stand for the density of the fluid, the absolute temperature, the specific heat, the thermal conductivity of the fluid, the heat of reaction, the initial concentration of the reactant species, the activation energy, the universal gas constant and the rate constant.

The temperature dependent viscosity $\bar{\mu}$ following the Reynolds model can be expressed as

$$\bar{\mu}=\mu_0e^{-\alpha(\bar{T}-T_w)} \tag{7}$$

wherein μ_0 is the constant dynamic viscosity of the fluid at $\bar{T}=T_W$

Introducing following non-dimensional variables and parameters

$$x=\frac{\bar{x}}{\lambda},\quad y=\frac{\bar{y}}{d},\quad u=\frac{\bar{u}}{c},\quad v=\frac{\bar{v}}{c}\quad,\quad t=\frac{c}{\lambda}\bar{t},\quad T=\frac{E(\bar{T}-T_W)}{RT_W^2}$$

$$h=\frac{\bar{H}}{d},\quad \phi=\frac{b}{d},\quad \mu=\frac{\bar{\mu}}{\mu_0},\ \beta=\frac{\alpha RT_W^2}{E},\quad \Pr=\frac{\mu c_p}{k},\quad \delta=\frac{d}{\lambda},$$

$$\mathrm{Re}=\frac{\rho cd}{\mu},\quad \varepsilon=\frac{RT_W}{E},\quad p=\frac{d^2}{c\lambda\mu_0}\bar{p},\quad \Gamma=\frac{SC_0AEd^2e^{\frac{-E}{RT_w}}}{kRT_w^2} \tag{8}$$

and using these non-dimensional variables and parameters into Eqs. (3-7) then we get

$$\delta\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{9}$$

$$\mathrm{Re}\left(\delta u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+2\delta^2\frac{\partial}{\partial x}\left[\frac{\mu}{(1+\lambda_1)}\frac{\partial u}{\partial x}\right]+\frac{\partial}{\partial y}\left[\mu\left(\delta\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right] \tag{10}$$

$$\mathrm{Re}\left(\delta u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+2\delta^2\frac{\partial}{\partial x}\left[\frac{\mu}{(1+\lambda_1)}\frac{\partial u}{\partial x}\right]+\frac{\partial}{\partial y}\left[\mu\left(\delta\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right] \tag{11}$$

$$\mathrm{Re}\Pr\left(\delta u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\delta^2\frac{\partial}{\partial x}\left[\delta^2\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right]+\Gamma\left[e^{\frac{T}{1+\varepsilon T}}\right] \tag{12}$$

where $\mu=e^{-\beta T}$ is the viscosity of the fluid, δ is the wave number, ε is the activation energy parameter, $\Pr$ is the Prandtl number, β is the viscosity parameter, Γ is the reaction parameter or Frank Kamenetskii parameter and Re is the Reynolds number.

Introducing the stream function by $u=\partial\psi/\partial y, v=\partial(\partial\psi/\partial x)$ and adopting the long wavelength procedure in Eqs. (9-12), we arrive at

$$\frac{\partial^2}{\partial y^2}\left[\left(\frac{\mu}{(1+\lambda_1)}\right)\frac{\partial^2\psi}{\partial y^2}\right]=0 \tag{13}$$

$$\frac{dp}{dx}=\frac{\partial}{\partial y}\left[\left(\frac{\mu}{(1+\lambda_1)}\right)\frac{\partial^2\psi}{\partial y^2}\right] \tag{14}$$

$$\frac{\partial^2 T}{\partial y^2}+\Gamma\left[e^{\frac{T}{1+\varepsilon T}}\right]=0 \tag{15}$$

Note that the incompressibility condition is clearly satisfied and $\partial p/\partial y = 0$ is given that $p \neq p(y)$.

The dimensionless form of the boundary conditions are given by

$$\psi = 0,\ \frac{\partial^2 \psi}{\partial y^2} = -1,\ T = 0 \quad \text{at} \quad y = 0 \tag{16}$$

$$\psi = F,\ \frac{\partial \psi}{\partial y} = -1,\ T = 0 \quad \text{at} \quad y = h = 1 + a\cos[2\pi x] \tag{17}$$

where $$F = \int_0^h \frac{\partial \psi}{\partial y} dy . \tag{18}$$

The respective dimensionless mean flow rates Q and F in the laboratory.

The relation of wave frames can be defined

$$Q = 1 + F \tag{19}$$

3. METHODS OF SOLUTION

The equations (13-15) are governing the fluid motion and heat transfer comprise non-linear and its closed form analytical solution is not possible. Hence we linearized this equations and the series expressions are constructed for small reaction parameter Γ. So we expand the quantities ψ , T, p and F as follows:

$$\psi = \psi_0 + \Gamma \psi_1 + \Gamma^2 \psi_2 + o(\Gamma^3), \tag{20}$$

$$T = T_0 + \Gamma T_1 + \Gamma^2 T_2 + o(\Gamma^3), \tag{21}$$

$$p = p_0 + \Gamma p_1 + \Gamma^2 p_2 + o(\Gamma^3), \tag{22}$$

$$F = F_0 + \Gamma F_1 + \Gamma^2 F_2 + o(\Gamma^3), \tag{23}$$

By using Eqs. (20-23) are substituting in Eqs.(13-15) ,using boundary conditions(16-17) and collecting the coefficients of like powers of Γ, we get the following systems:

3.1 Zeroth order system

$$\frac{\partial^2}{\partial y^2}\left[e^{-\beta T_0} \frac{\partial^2 \psi_0}{\partial y^2} \right] = 0 \tag{24}$$

$$\frac{dp_0}{dx} = \frac{\partial}{\partial y}\left[e^{-\beta T_0} \frac{\partial^2 \psi_0}{\partial y^2} \right] \tag{25}$$

$$\frac{\partial^2 T_0}{\partial y^2} = 0 \tag{26}$$

$$\psi_0 = 0,\ \frac{\partial^2 \psi_0}{\partial y^2} = 0,\ T_0 = 0 \quad \text{at} \quad y = 0 \tag{27}$$

$$\psi_0 = F_0,\ \frac{\partial \psi_0}{\partial y} = -1,\ T_0 = 0 \quad \text{at} \quad y = h \tag{28}$$

3.2 First order system

$$\frac{\partial^2}{\partial y^2}\left[e^{-\beta T_0}\left(\frac{\partial^2 \psi_1}{\partial y^2} - \beta T_1 \frac{\partial^2 \psi_0}{\partial y^2} \right) \right] = 0 \tag{29}$$

$$\frac{dp_1}{dx} = \frac{\partial}{\partial y}\left[e^{-\beta T_0}\left(\frac{\partial^2 \psi_1}{\partial y^2} - \beta T_1 \frac{\partial^2 \psi_0}{\partial y^2} \right) \right] \tag{30}$$

$$\frac{\partial^2 T_1}{\partial y^2} + e^{\frac{T}{1+\varepsilon T}} = 0 \tag{31}$$

$$\psi_1 = 0,\ \frac{\partial^2 \psi_1}{\partial y^2} = 0,\ T_1 = 0 \quad \text{at} \quad y = 0 \tag{32}$$

$$\psi_1 = F_1,\ \frac{\partial \psi_1}{\partial y} = 0,\ T_1 = 0 \quad \text{at} \quad y = h \tag{33}$$

3.3 Second order system

$$\frac{\partial^2}{\partial y^2}\left[e^{-\beta T_0}\left(\frac{\partial^2 \psi_2}{\partial y^2} - \beta T_1 \frac{\partial^2 \psi_1}{\partial y^2} + \frac{1}{2}\beta (T_1 \beta - 2T_2) \frac{\partial^2 \psi_0}{\partial y^2} \right) \right] = 0 \tag{34}$$

$$\frac{dp_2}{dx} = \frac{\partial}{\partial y}\left[e^{-\beta T_0}\left(\frac{\partial^2 \psi_2}{\partial y^2} - \beta T_1 \frac{\partial^2 \psi_1}{\partial y^2} + \frac{1}{2}\beta (T_1 \beta - 2T_2) \frac{\partial^2 \psi_0}{\partial y^2} \right) \right] \tag{35}$$

$$\frac{\partial^2 T_1}{\partial y^2}+\frac{T_1 e^{\frac{T}{1+\varepsilon T}}}{(1+\varepsilon T_0)^2}=0 \tag{36}$$

$$\psi_2=0,\ \frac{\partial^2\psi_2}{\partial y^2}=0,\ T_2=0 \quad \text{at} \quad y=0 \tag{37}$$

$$\psi_2=F_2,\ \frac{\partial\psi_2}{\partial y}=0,\ T_2=0 \quad \text{at} \quad y=h \tag{38}$$

3.4 Solution of Zeroth order

Solving the Eqs. (24-28) of above systems , we get

$$\psi_0=\frac{h^2(3F+h)y-(3F+h)y^3}{2h^3(1+\lambda_1)},$$

$$\frac{dp_0}{dx}=\frac{-(3F+h)}{h^3(1+\lambda_1)^2},$$

$$T_0=0$$

3.5 Solution of First order

Eqs. (29-33) are solving then we have

$$\psi_1=\frac{3\beta(F+h)y^3}{2h^3(1+\lambda_1)}\left[\frac{3y^4-5hy^3+18h^2y^2-16h^4}{120}\right],$$

$$\frac{dp_1}{dx}=\frac{(3F+h)}{h^3(1+\lambda_1)^2}\left(\frac{9h^2\beta}{10}\right),$$

$$T_1=\frac{(h-y)y}{2}.$$

3.6 Solution of Second order

Solving the Eqs. (34-38) of above systems

$$\psi_2=\frac{-3\beta(F+h)y}{h^3(1+\lambda_1)}\left[\frac{50(3\beta-2)y^6-140(3\beta+2)hy^5+1449\beta h^2y^4-70(27\beta-5)h^3y^3+(1482\beta+265)h^4y^2-(2661\beta-185)h^6}{50400}\right]$$

$$\frac{dp_2}{dx}=\frac{(3F+h)}{h^3(1+\lambda_1)^2}\left[\frac{7000(3\beta-2)y^6-33600\beta hy^3+630h^2y^2(23+33\beta)-15120\beta h^3y+(1482\beta+265)h^4}{8400}\right]$$

$$T_2=\frac{(y^3-2hy^2+h^3)y}{24}$$

Solution of the above systems and using $F_0 = F - \Gamma F_1 - \Gamma^2 F_2$ the expressions of the stream function, axial pressure gradient and temperature profile upto $o(\Gamma^3)$ may be expressed as follows:

$$\psi=\frac{1}{(1+\lambda_1)}\left(\frac{h^2(3F+h)y-(F+h)y^3}{2h^3}\right)+\frac{3\beta(F+h)y}{h^3(1+\lambda_1)}$$
$$\times\left[\left(\frac{3y^4-5hy^3+18h^2y^2-16h^4}{120}\right)\Gamma-\frac{1}{50400}\left(\begin{array}{l}50(3\beta-2)y^6-140(3\beta+2)hy^5+1449\beta h^2y^4-70(27\beta-5)h^3y^3\\+(1482\beta+265)h^4y^2-(2661\beta-185)h^6\end{array}\right)\Gamma^2\right] \tag{39}$$

$$\frac{dp}{dx}=\frac{-3(F+h)}{(1+\lambda_1)^2h^3}\left[1-\left(\frac{9h^2\beta}{10}\right)\Gamma-\frac{\beta}{8400}\left(\begin{array}{l}7000(3\beta-1)y^4-33600\beta hy^3\\+630h^2y^2(23-33\beta)-15120\beta h^3y+(1482\beta+265)h^4\end{array}\right)\Gamma^2\right] \tag{40}$$

$$T=\left(\frac{y(h-y^2)}{2}\right)\Gamma+\left(\frac{y^4-2hy^3+h^3y}{24}\right)\Gamma^2 \tag{41}$$

The heat transfer coefficient at $y=h$ is

$$Z=\left(\frac{\partial h}{\partial x}\right)\left(\frac{\partial T}{\partial y}\right) \tag{42}$$

The expression for the pressure rise per wavelength Δp and the frictional force F_λ at the wall are computed as

$$\Delta p=\int_0^1\left(\frac{dp}{dx}\right)dx \tag{43}$$

$$F_\lambda=\int_0^1\left(-h\frac{dp}{dx}\right)dx \tag{44}$$

where pressure gradient dp/dx is given in Eqs. (40)

4. RESULTS AND DISCUSSIONS

The behavior of pressure rise, pressure gradient, velocity profile, temperature and heat transfer coefficient profiles are graphically discussed for different values of patient parameters i.e., the reaction parameter Γ , β is the viscosity parameter , ratio of relaxation to retardation times λ_1 and the activation energy parameter ε .

Figs. (1)-(3) display the effects of λ_1, Γ and β for axial velocity against y. The effect of the ratio of relaxation to retardation times λ_1 is shown in Fig. 1. We note that with the increase in λ_1 velocity profile increases in the peristaltic pumping region. The effect of the reaction parameter Γ is shown in Fig. 2. We examined that with the increase in Γ velocity profile increases. In Fig. 3. the effects of viscosity parameter β are shown. We observed that the amplitude of velocity profile increases by increasing the viscosity parameter.

The variation of pressure rise with flow rate is shown in Figs.(4)-(6).for different values of λ_1, Γ and β. The study of the ratio of relaxation to retardation times λ_1 is shown in Fig.4. We note that with the increase in λ_1 pressure rise decreases in the peristaltic pumping region. The effect of the reaction parameter Γ is shown in Fig. 5. We observed that with the increase in Γ pressure rise decreases. In Fig. 6. the effects of viscosity parameter β are shown. We examined that the pressure rise decreases by increasing the viscosity parameter.

Eq. (41) is used to draw Figs.(7)-(8) which represents the effects of reaction parameter Γ and activation energy parameter ε on temperature profile T . Fig. 7 shows that the amplitude of temperature profile T increases by increasing the reaction parameter Γ.This depicts that an increase in the reaction parameter Γ strengthens the reaction term in the temperature equation which results an increase in the amplitude of temperature profile T . On the other hand, increasing values of activation energy parameter ε decreases the amplitude of the temperature profile T (see Fig. 8).

Fig. 9 is drawn to analyze the influence of increasing reaction parameter Γ and viscosity parameter β on friction force with Q. This Fig.9 illustrates that the friction force shows a reverse behavior when compared with the pressure drop . After examining Fig. 10 we concluded that critical value Q_h increases when either of β is increased.

Figs. (11)-(12) presents the variations of Γ and ε on heat transfer coefficient at the wall($y = h$). In Fig. 11 we deduce that the heat transfer coefficient has an oscillatory behavior which may be due peristalsis, that is, the heat transfer coefficient is negative for negative values of x and positive for positive values of x. The absolute value of the heat transfer coefficient (Z) increases by increasing reaction parameter Γwhile it decreases by increasing activation energy parameter ε .

The variations in axial pressure gradient within one wavelength $x \in (0.1)$are presented in Figs.(13)-(15). In Fig.15. illustrates that the pressure gradient is small in the wider part of the channel . This depicts that the fluid can easily flow without the imposition of large pressure gradient. Moreover, in this part of the channel negative and increases with an increase in viscosity parameter . On the other hand the pressure gradient is large in the narrow part of the channel which express that a much larger pressure is required to move the fluid with same flux. In this part of the channel is positive and decreases due to an increase in (Fig. 15). The effects of increasing reaction parameter on can be seen through Fig. 14. Here we noticed that the effects of on are copy of the effects of β. We prepared Fig. 13 to analyze the behavior of the ratio of relaxation to retardation times λ_1 on pressure gradient . This Fig.13 depicts that an increase in λ_1 leads to a decrease in dp/dx in the wider part of channel.

TRAPPING PHENOMENA

Trapping is another interesting phenomenon of peristalsis in which streamlines under certain conditions split to trap a bolus. This trapped bolus pushed ahead along with the peristaltic wall with the likewise speed of wave. The effects of β , Γ, ε and f λ_1 on trapping can be seen through the Figs. (16-19). Fig.16 displays that the volume of trapped bolus increases with an increase in the viscosity parameter β. This observation also remains true for Fig. 17 which depicts the effects of reaction parameter Γ a on trapping. Streamlines patterns in Fig. 18 indicate that the volume of the trapped bolus decreases due to an increase in the values of the activation energy parameter ε. Fig.19 displays that the volume of trapped bolus increases with an increase in the ratio of relaxation to retardation times λ_1.

CONCLUSION

In the present paper we have discussed the effect of temperature dependent viscosity on the peristaltic transport of a Jeffrey fluid.
The investigation of present study the main observations are given below.

1. The peristaltic pumping region narrows down in response to the increasing the ratio of relaxation to retardation times λ_1.
2. An increase in of β , Γ and λ_1 in increases the amplitude of velocity u .
3. In the wider part of the channel dp/dx increases in response to the increasing β , Γ and λ_1 whereas it decreases in the narrow part of the channel.
4. The amplitude of temperature T increases with increasing reaction Γ parameter and decreases by increasing activation energy parameter ε
5. The absolute value of heat transfer coefficient increases/decreases when temperature increases/decreases.
6. The volume of trapped bolus increases by increasing β , Γ, ε and λ_1 .

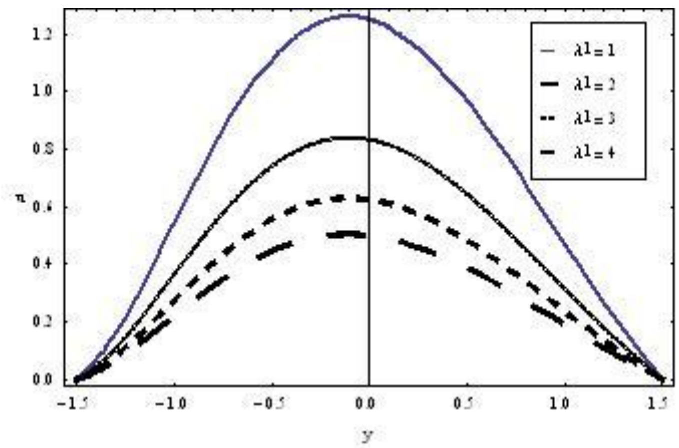

Fig 1.Plots of velocity distibutoion u versus y for different values of λ_1.

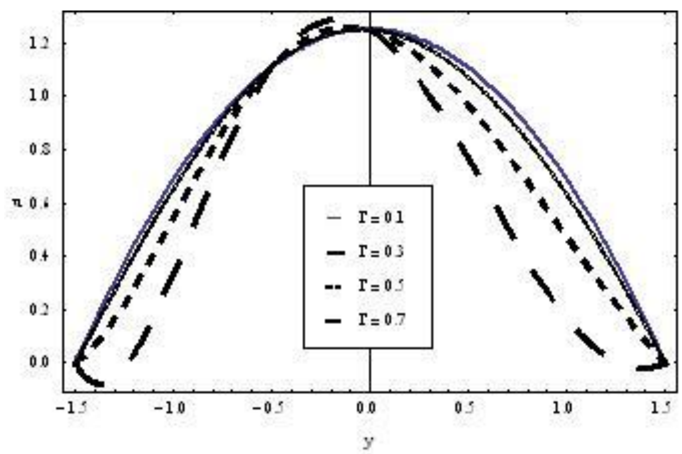

Fig 2.Plots of velocity distibutoion u versus y for different values of Γ.

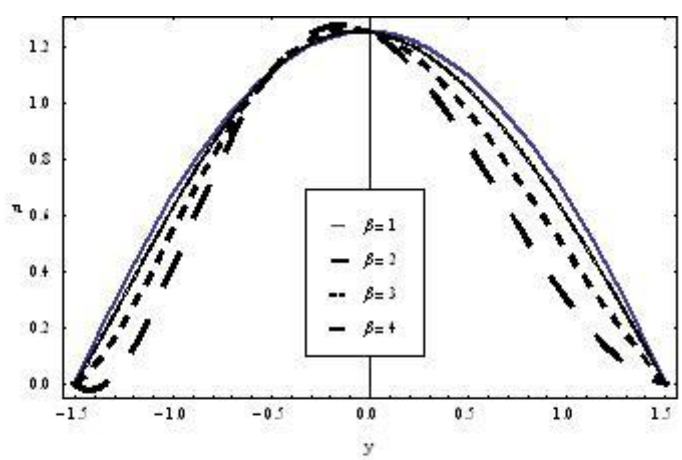

Fig 3.Plots of velocity distibutoion u versus y for different values of β.

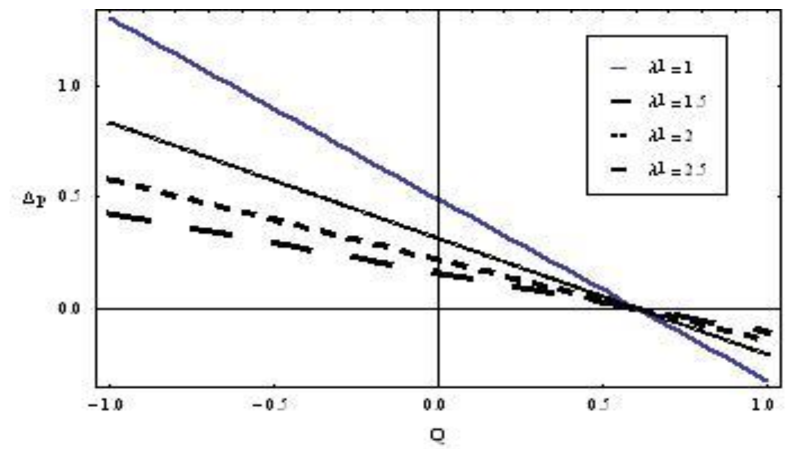

Fig 4.Plots of pressure rise per wavelength Δp versus flow rate Q for different values of λ_1.

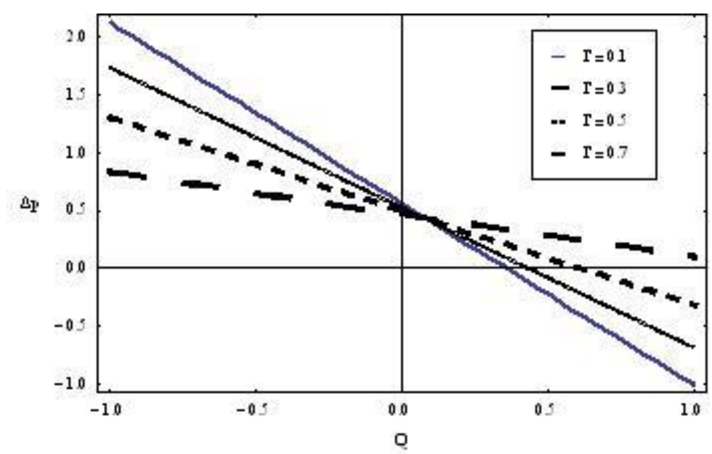

Fig 5.Plots of pressure rise per wavelength Δp versus flow rate Q for different values of Γ.

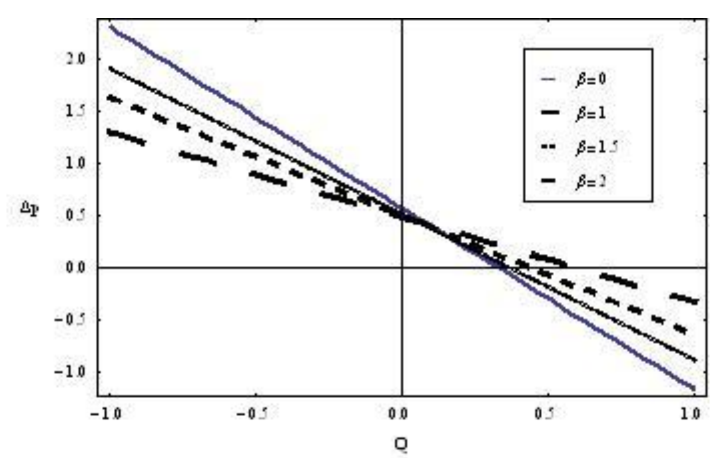

Fig 6.Plots of pressure rise per wavelength Δp versus flow rate Q for different values of β.

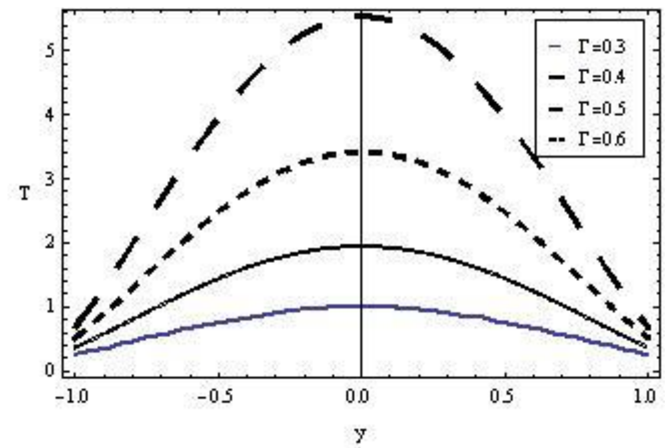

Fig 7.Plots of temperature T versus y for different values of Γ.

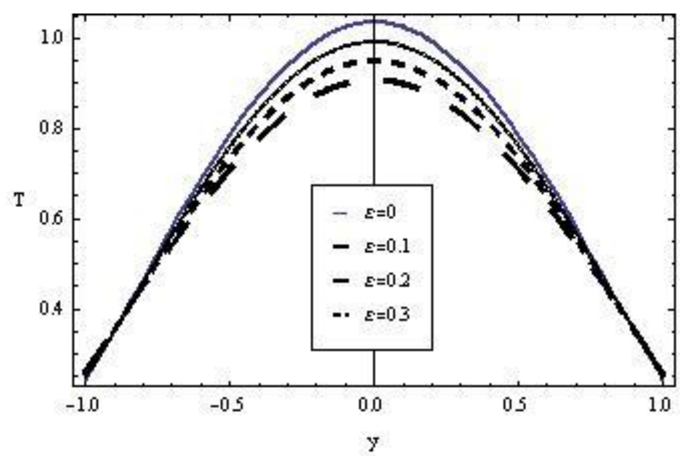

Fig 8.Plots of temperature T distibutoion versus y for different values of ε.

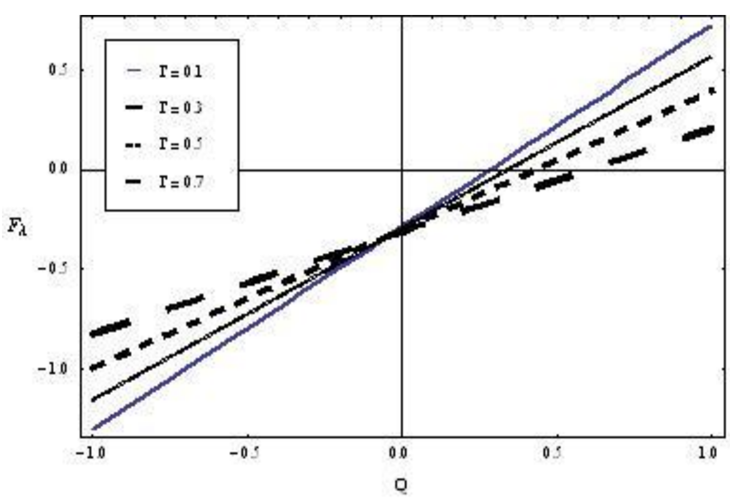

Fig 9.Plots of frictional force F_{λ} versus flow rate Q for different values of Γ.

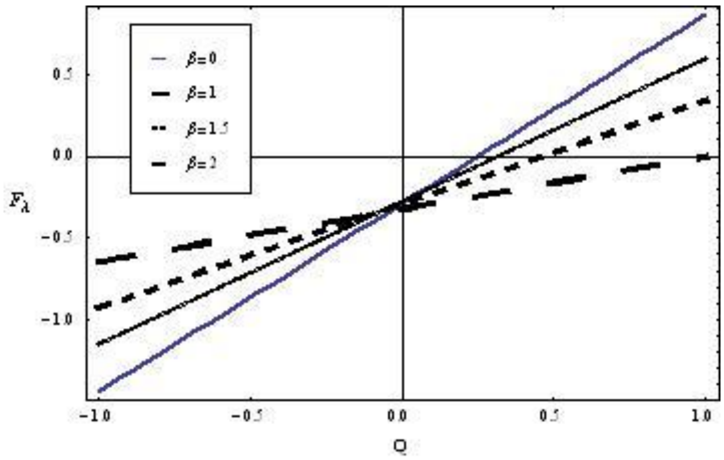

Fig 10.Plots of frictional force F_λ versus flow rate Q for different values of β.

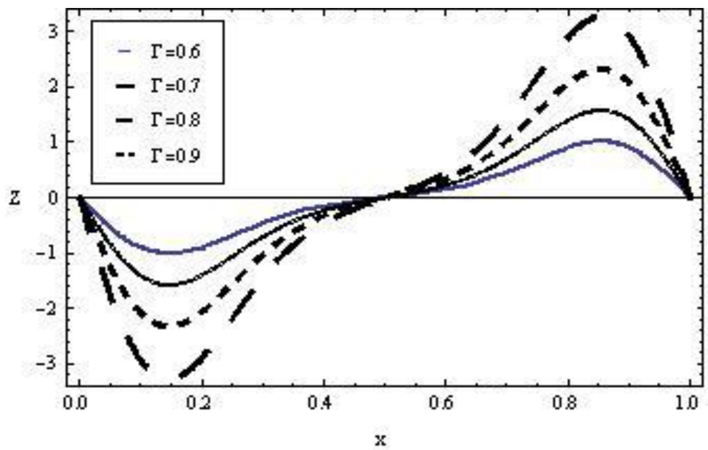

Fig 11.Plots of heat transfer coefficent at the wall Z versus x for different values of Γ.

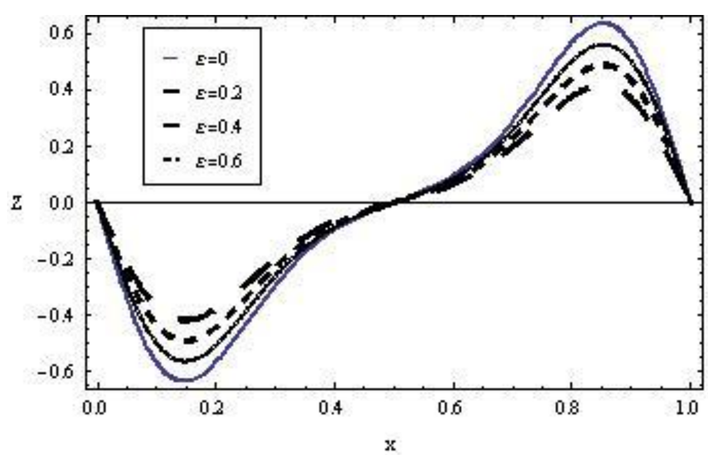

Fig 12.Plots of heat transfer coefficent at the wall Z versus x for different values of ε.

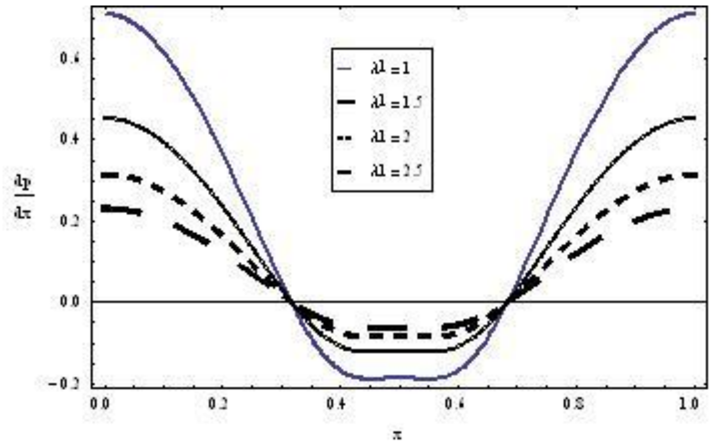

Fig 13.Plots of pressure gradient dp/dx versus x for different values of λ_1.

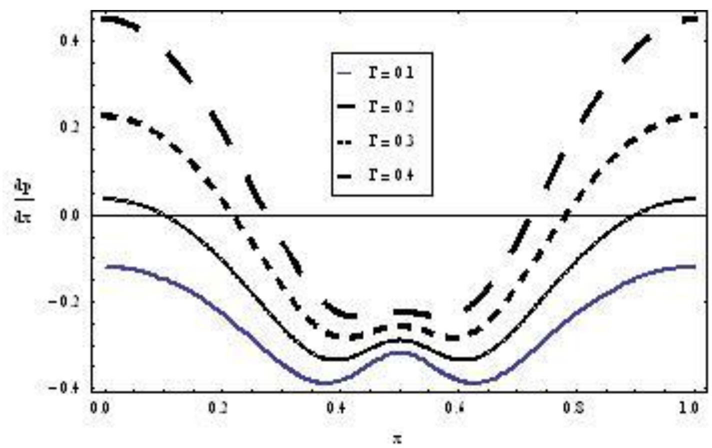

Fig 14.Plots of pressure gradient dp/dx versus x for different values of Γ.

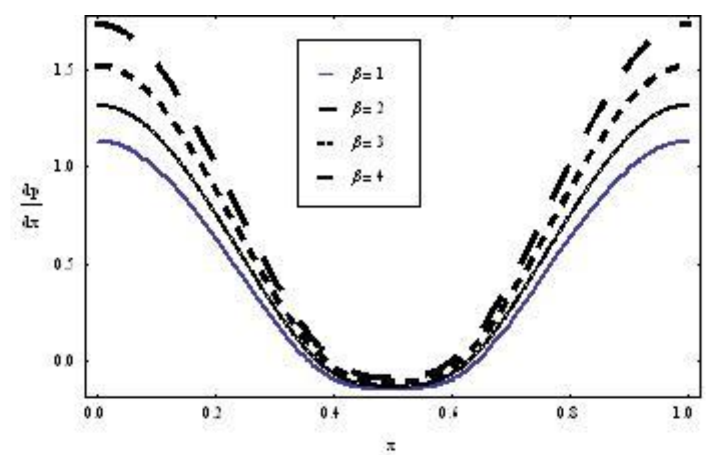

Fig 15.Plots of pressure gradient dp/dx versus x for different values of β.

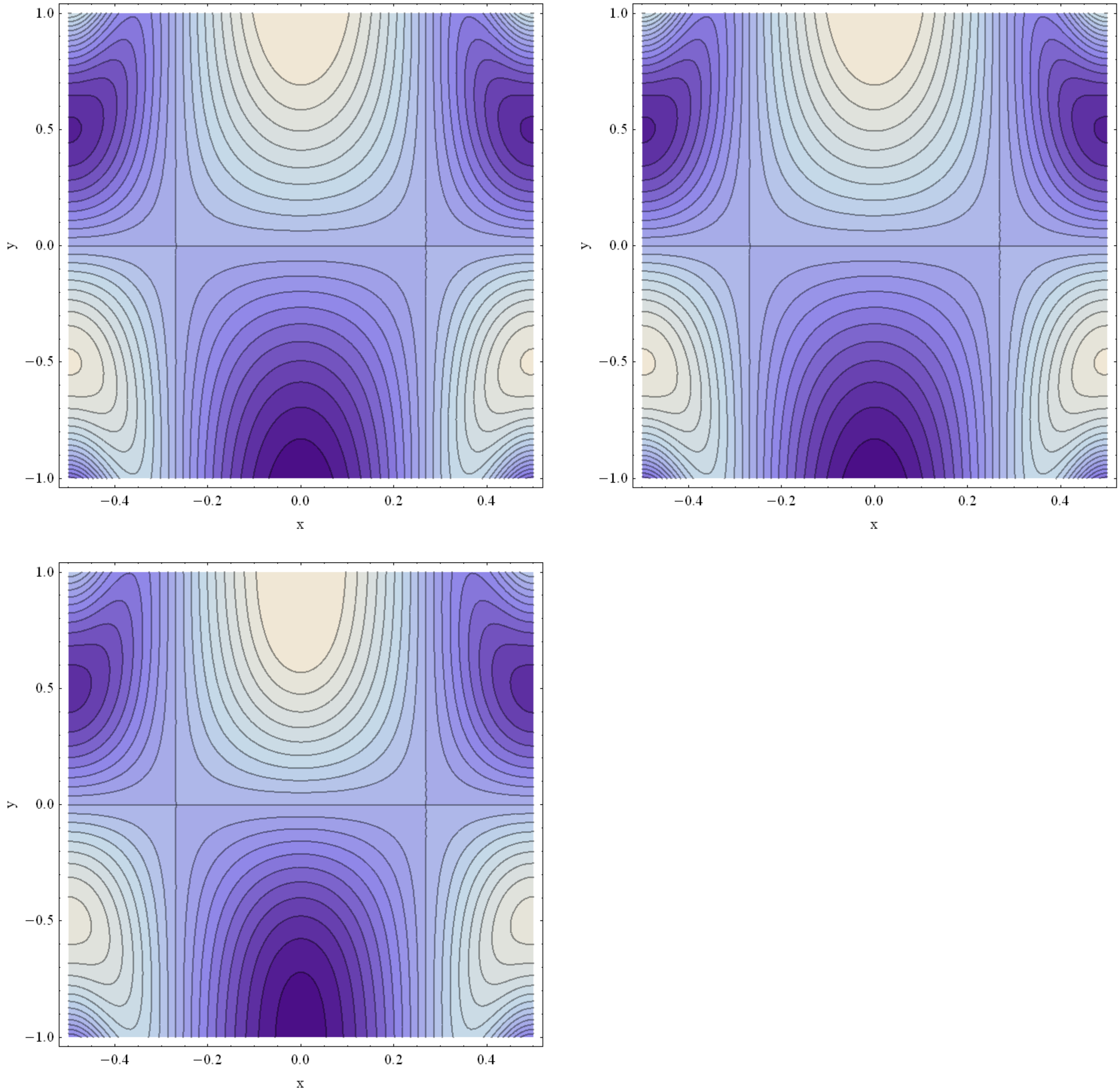

Fig.16. Streamlines for viscosity parameter β =3, β =4, β =5 with $a = 0.5, \lambda_1 = 1, \Gamma = 0.5, \varepsilon = 1, Q = 0.06$.

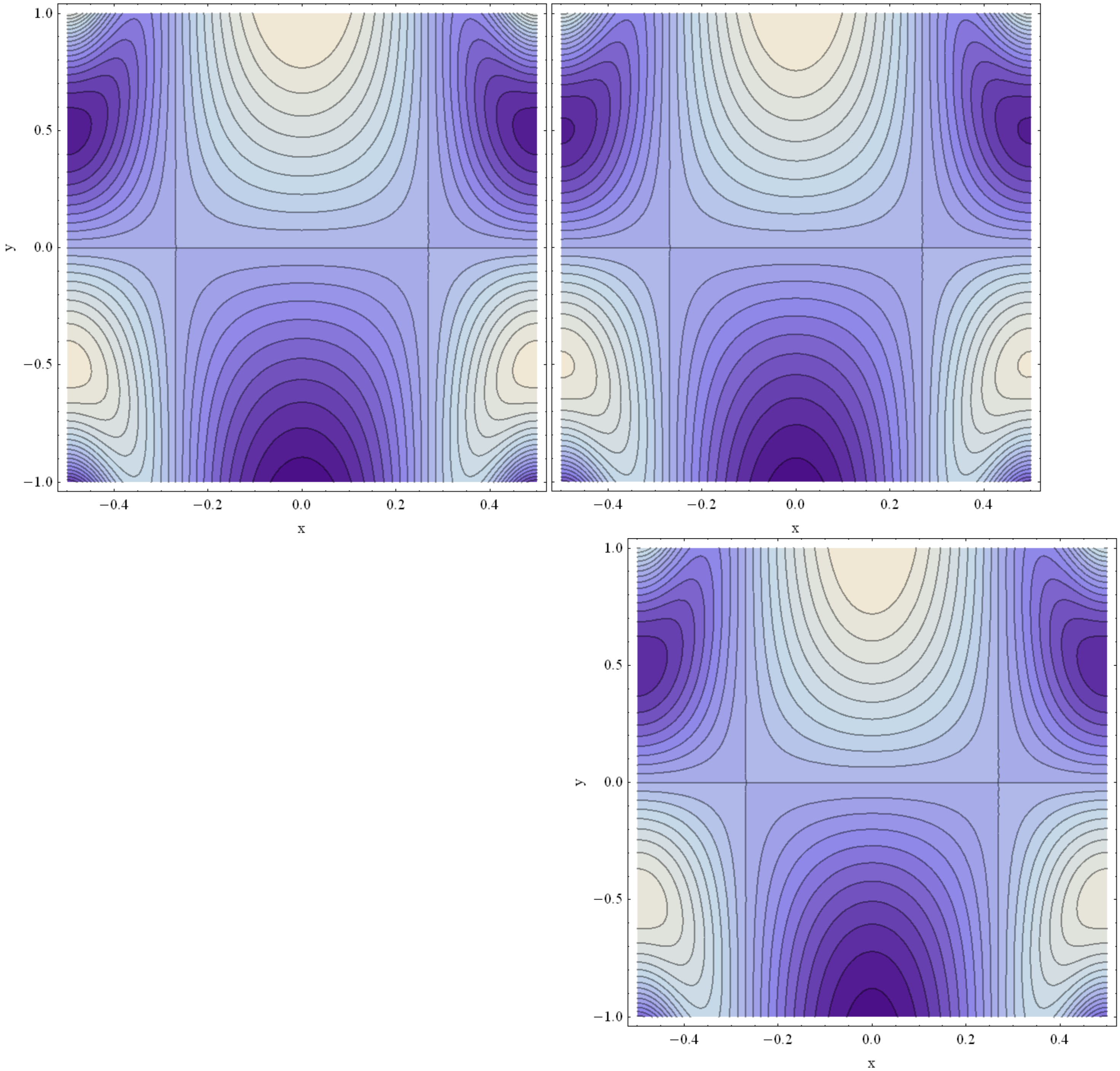

Fig.17. Streamlines for reaction parameter Γ=0.3, Γ=0.5, Γ=0.7 with
$a = 0.5, \lambda_1 = 1, \beta = 2, \varepsilon = 1, Q = 0.06$.

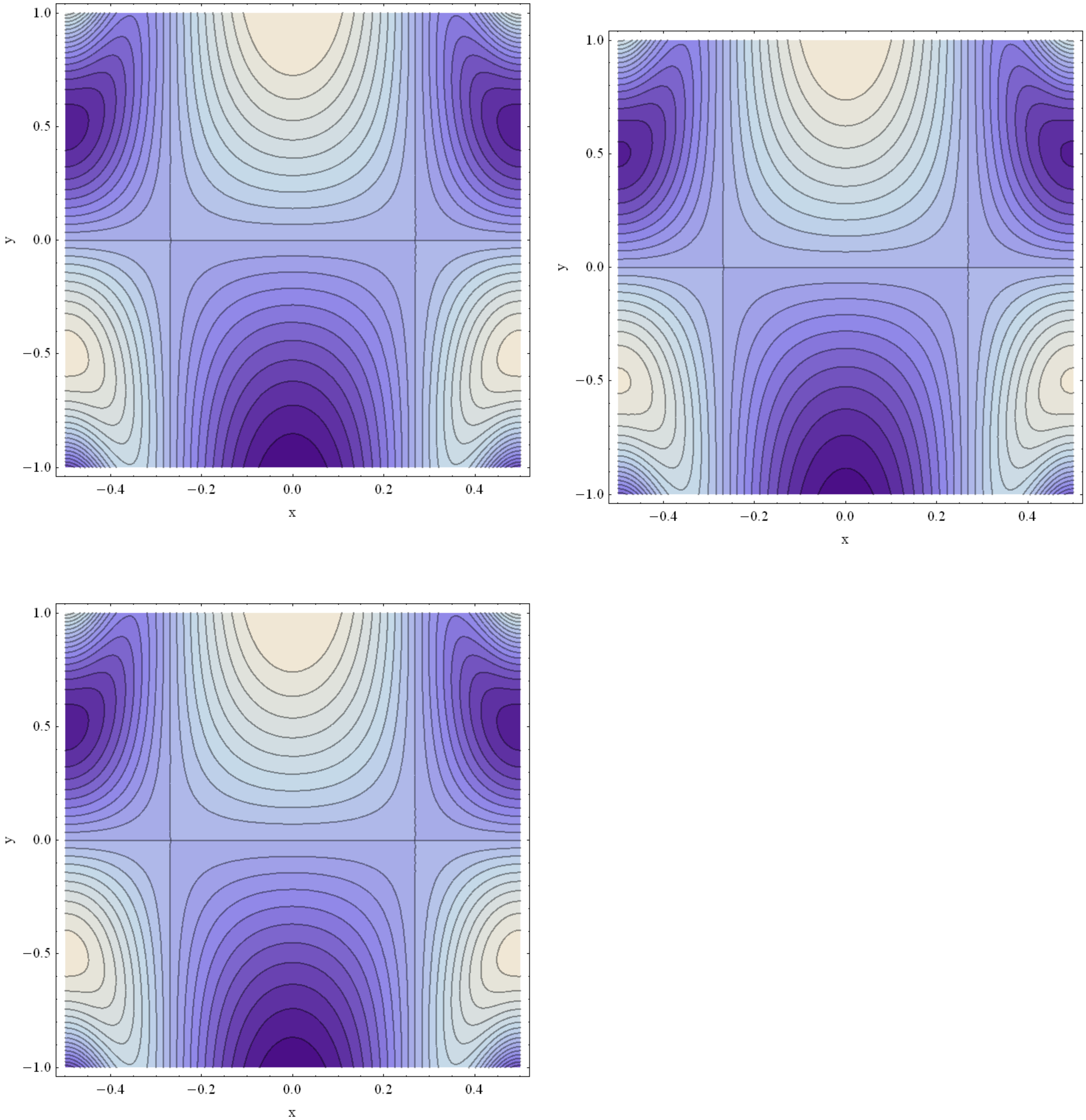

Fig.18. Streamlines for activation energy parameter ε =2, ε =2.5, ε =3 with $a = 0.5, \lambda_1 = 1, \beta = 2, \Gamma = 0.5, Q = 0.06$.

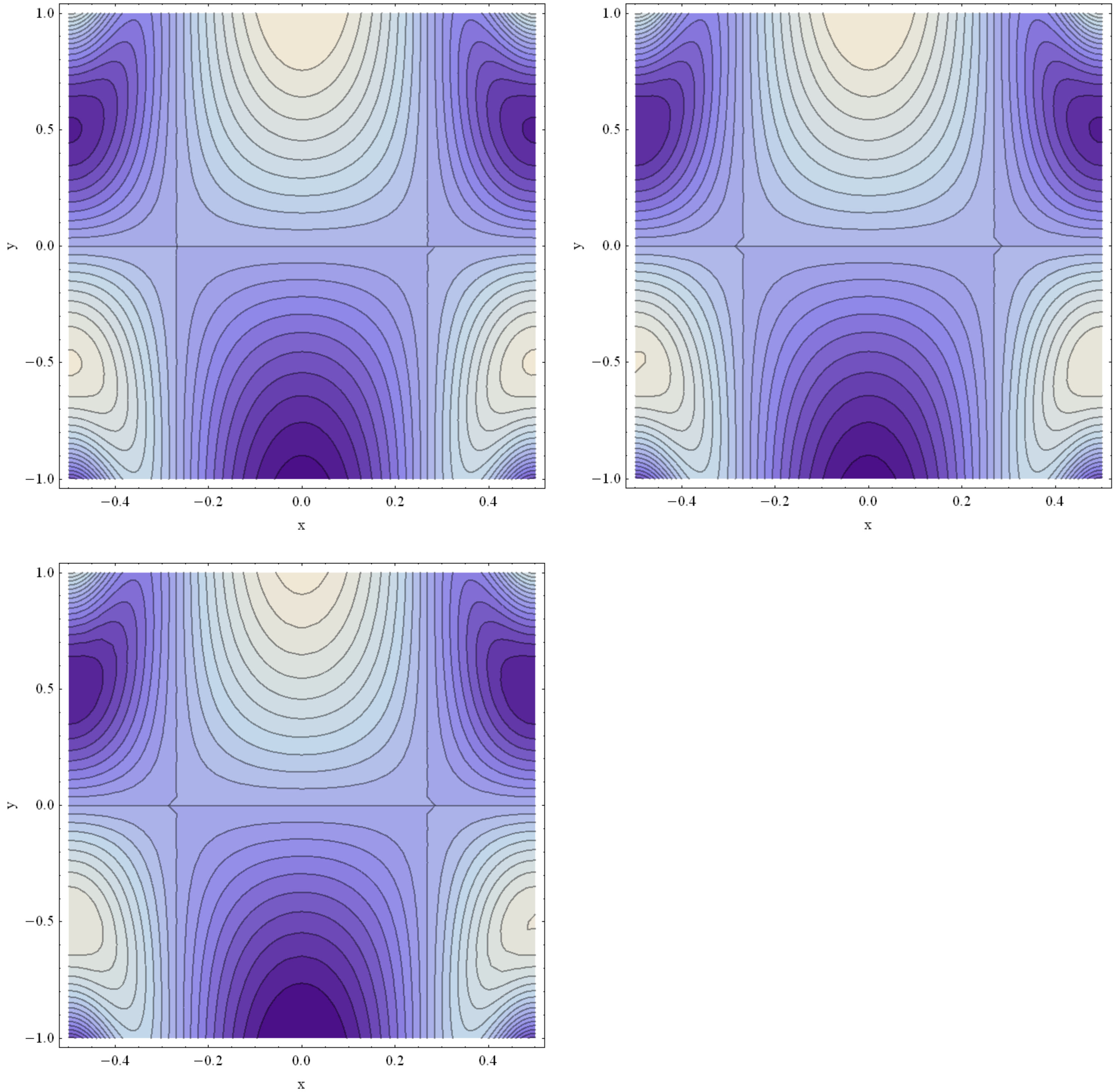

Fig.19. Streamlines for ratio of relaxation to retardation times λ_1 =2, λ_1 =4, λ_1 =6 with $a = 0.5, \varepsilon = 1, \beta = 2, \Gamma = 0.5, Q = 0.06.$

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