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Review Article

The Binary Powell-Eyring Nanofluid of Peristaltic Flow with Heat Transfer in a Ciliated Tube

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Abstract: These articles show the mathematical investigation of the binary Powell- Eyring Nanofluid of peristaltic flow with heat transfer in a ciliated tube. The approximation of long wavelength and low Reynolds number is taken into consideration. We obtain a system of partial differential equations which solved by using the perturbation method. The velocity and the temperature are computed for various values of the physical parameters. The results are illustrated graphically through a set of Figures. We found that the increase of Grashof number causes an increase in the velocity, then the velocity decrease near the wall of the tube. When the volume fraction of the Nanoparticles increase the velocity increase and decrease near the wall of the tube. The increase in the cilia length leads to an increase in the velocity, then a decrease near the wall of the tube. The increase of the first Eyring-Powell parameter gives an increase in the velocity and decrease near the wall of the tube. The increase of the second Eyring-Powell parameter cause decrease in the velocity. The temperature parameter increase then decreases with the increase of the Sink parameter. The increase of the volume fraction of the Nanoparticles leads to decreases then increase in the temperature parameter. The increase of the cilia length parameter causes an Increase in the temperature.

Keywords: Nanofluid, Perturbation Method, Eyring- Powell Model, Peristaltic Flow and Heat Transfer

1. Introduction

Peristaltic is a well-known mechanism to pump the fluid which generated contraction and relaxation due to change in pressure along the wall of the tube. Such mechanism occurs widely in many biological and biomedical systems. It play an important role in the human body such as the passage of urine from the kidneys to bladder through the ureter, swallowing food through the esophagus, the movement of spermatozoa in the ducts afferents of the male reproductive tract, transport of chime in the gastro-intestinal tract, the passage of ovum in the female fallopian tube, the transport of feces in the large intestine, Venules and tube capillaries involve peristaltic motion, peristaltic phenomenon plays an important role of biomedical instruments like heart-lung machines, artificial heart and ortho machines, dialysis machines and transport of toxic material waste inside the sanitary ducts, also peristaltic is used in nuclear industry. In the past few decades several experimental and theoretical investigations have been made to understand peristalsis in different situations. The fluid motion in the peristaltic pump discussed [1]. The problems of peristaltic flow are discussed [2-4] in a different flow. The combined effect of heat and mass transfer on two-dimensional peristaltic transport of a couple-stress fluid which is electrically conducting through a porous medium in the presence of a uniform magnetic field, and in the presence of heat absorption in an inclined asymmetric channel is studied [5]. The Eyring-Powell peristaltic fluid flow with heat and mass transfer in cylindrical coordinates for fixed and moving frame have been investigated [6]. The peristaltic flow of a Jeffrey fluid in a vertical porous stratum with heat transfer is studied [7] under long wavelength and low Reynolds number assumptions. The influence of heat and mass transfer on peristaltic flow through a porous space in the presence of the magnetic field with compliant walls is investigated [8]. MHD peristaltic flow of a conducting fluid with heat transfer in a vertical asymmetric channel through a porous medium analyzed [9]. The effect of slip and heat transfer on peristaltic transport of Jeffery fluid in a vertical asymmetric porous channel is given [10]. The study of peristaltic transport of a Newtonian fluid in an asymmetric channel is examined [11]. The peristaltic transport of a magneto Non-Newtonian fluid through a porous medium in a horizontal finite channel investigated [12]. Nanofluid research is now an intense area of research for engineers and scientists. Nanofluids play a vital role in the optical field, biomedical, electronic, industrial cooling applications, petroleum reservoirs, fiber and granular insulation, nuclear reactors, and chemical catalytic reactors. An important characteristic of nanofluids is its ability to conduct high thermal conductivity with respect to base fluids. The researchers on this topic are quite extensive may be made to some recent studies such as the radiative flow of Powell-Eyring magneto-Nanofluid over a stretching cylinder with chemical reaction and double stratification near a stagnation point is an investigation [13]. The effect of magnetohydrodynamic metallic nanoparticles blood flow through a stenotic artery is discussed [14]. The effect of binary Nanofluids and chemical surfactants on absorption performance is discussed [15]. The pulsatile flow of non-Newtonian Nanofluid in a porous space with thermal radiation and application to the blood flow is analyzed [16]. Nanofluid film flow of Eyring- Powell fluid with magnetohydrodynamic effect on the unsteady porous stretching sheet has observed [17]. The trapping study of Nanofluids in an annulus with cilia has examined [18]. Powell and Eyring developed a complex mathematical model, known as Eyring-Powell model, this model is used in many research like the effect of the hall and ion slip-on peristaltic blood flow of Eyring-Powell fluid in a non-uniform porous channel which studied [19]. The flow of an Eyring –Powell non-Newtonian fluid over a stretching sheet is investigated [20]. The radiative effects in a three-dimensional flow of MHD Eyring- Powell fluid are discussed [21]. The numerical study of magnetohydrodynamic generalized Couette flow of Eyring–Powell fluid with heat transfer and slip condition has Studied [22]. The flow of an Eyring–Powell model between coaxial cylinders with variable viscosity has been analyzed [23]. The steady flow of an Eyring – Powell fluid over a moving surface with convective boundary conditions is discussed [24]. The momentum and heat transfer of a Non-Newtonian Eyring-Powell fluid over a Non-Isothermal stretching sheet is studied [25]. The aim of the present work is to analyze the effect of binary Nanofluids and cilia on the peristaltic flow of Eyring-Powell fluid in the tube. We will solve the momentum and energy equations and discusses the resultis.

2. Mathematial Modzel

We considered the ciliary motion for an incompressible Nanofluid. The equations of motion for the Eyring-Powell model take the following form.

$$\overline{\nabla}.\overline{V} = 0, \tag{1}$$

$$\rho_{nf}(\frac{\partial \overline{V}}{\partial \bar{t}}) = -\nabla \overline{P} + \nabla.\overline{S} + g(\rho\beta)_{nf}(\overline{T} - T_1), \tag{2}$$

$$(\rho c_p)_{nf}(\frac{\partial \overline{T}}{\partial t} + \underline{V} \cdot \underline{\nabla T}) = K_{nf}\nabla^2 \overline{T} + Q_0, \tag{3}$$

$$\overline{S}_{ij} = \frac{1}{\mu_{nf}} A_1 + \frac{1}{\beta_1 \dot{\gamma}} Sinh^{-1}(\frac{\dot{\gamma}}{d}) A_1, \tag{4}$$

$$\dot{\gamma} = \sqrt{\frac{1}{2} tr\left(A_1\right)^2} \tag{5}$$

$$Sinh^{-1}(\frac{\dot{\gamma}}{d}) \cong \frac{\dot{\gamma}}{d} - \frac{1}{6d^3}\dot{\gamma}^3, \quad \left|\frac{\dot{\gamma}}{d}\right| \langle\langle\langle 1 \tag{6}$$

$$A_1 = \underline{L} + \underline{L}^T, \underline{L} = grad \quad \overline{V} \tag{7}$$

Where ρ_{nf} represent the density of Nanofluid, $\overline{V}$ the velocity field, $\left(\rho c_p\right)_{nf}$ the effective heat capacitance of Nanofluid, K_{nf} the thermal conductivity of Nanofluid, $\left(\rho B\right)_{nf}$ the thermal expansion coefficient of Nanofluid, Q_0 the coefficient of heat source, P the pressure, $\overline{T}$ the temperature of the fluid, $\overline{T}_1$ the temperature of the outer tube, μ_{nf} the dynamic viscosity of Nanofluid, β_1 and d represent the characteristic of Eyring-Powell model and A_1 the Rivlin- Erickson tensor.

3. Mathematical Formulation of the Problem

For the peristaltic flow of an incompressible Nanofluid in a uniform tube, using the cylindrical coordinate $(\overline{R}, \overline{Z})$ where $\overline{Z}$ the axis of the tube, while $\overline{R}$ the radius of it see Figure 1. The flow are described in two coordinate systems one is fixed and the other moving with speed c. The governing equations in the fixed frame are given as

$$\frac{\partial \overline{U}}{\partial \overline{R}} + \frac{\overline{U}}{\overline{R}} + \frac{\partial \overline{W}}{\partial \overline{Z}} = 0 \tag{8}$$

$$\rho_{nf}(\frac{\partial \overline{U}}{\partial \bar{t}} + \overline{U}\frac{\partial \overline{U}}{\partial \overline{R}} + \overline{W}\frac{\partial \overline{U}}{\partial \overline{Z}}) = -\frac{\partial \overline{P}}{\partial \overline{R}} + \frac{1}{\overline{R}}\frac{\partial}{\partial \overline{R}}(\overline{R}\overline{S}_{\overline{R}\overline{R}}) + \frac{\partial \overline{S}_{\overline{R}\overline{Z}}}{\partial \overline{Z}} - \frac{\overline{S}_{\overline{\theta}\overline{\theta}}}{\overline{R}}, \tag{9}$$

$$\rho_{nf}(\frac{\partial \overline{W}}{\partial \bar{t}} + \overline{U}\frac{\partial \overline{W}}{\partial \overline{R}} + \overline{W}\frac{\partial \overline{W}}{\partial \overline{Z}}) = -\frac{\partial \overline{P}}{\partial \overline{Z}} + \frac{1}{\overline{R}}\frac{\partial}{\partial \overline{R}}(\overline{R}\overline{S}_{\overline{R}\overline{Z}}) + \frac{\partial \overline{S}_{\overline{Z}\overline{Z}}}{\partial \overline{Z}} + (\rho\beta)_{nf}\, g(\overline{T} - \overline{T}_0), \tag{10}$$

$$(\rho c_p)_{nf}\left(\frac{\partial \overline{T}}{\partial \overline{t}}+\overline{U}\frac{\partial \overline{T}}{\partial \overline{R}}+\overline{W}\frac{\partial \overline{T}}{\partial \overline{Z}}\right)=K_{nf}\left(\frac{1}{\overline{R}}\frac{\partial}{\partial \overline{R}}\left(\overline{R}\frac{\partial \overline{T}}{\partial \overline{R}}\right)+\frac{\partial^2 \overline{T}}{\partial \overline{Z}^2}\right)+Q_0 \tag{11}$$

Where

$$\overline{S}_{\overline{R}\overline{R}}=[(\mu_{nf}+\frac{1}{\beta d})-6\frac{1}{\beta d^3}\dot{\gamma}^2](2\frac{\partial \overline{U}}{\partial \overline{R}}),\ \overline{S}_{\overline{R}\overline{Z}}=[(\mu_{nf}+\frac{1}{\beta d})-6\frac{1}{\beta d^3}\dot{\gamma}^2](\frac{\partial \overline{U}}{\partial \overline{Z}}+\frac{\partial \overline{W}}{\partial \overline{R}}),$$

$$\overline{S}_{\overline{\theta}\overline{\theta}}=[(\mu_{nf}+\frac{1}{\beta d})-6\frac{1}{\beta d^3}\dot{\gamma}^2](2\frac{\overline{U}}{\overline{R}}),\ \overline{S}_{\overline{Z}\overline{Z}}=[(\mu_{nf}+\frac{1}{\beta d})-6\frac{1}{\beta d^3}\dot{\gamma}^2](2\frac{\partial \overline{W}}{\partial \overline{R}}),$$

$$\dot{\gamma}^2=[2(\frac{\partial \overline{U}}{\partial \overline{R}})^2+2(\frac{\partial \overline{W}}{\partial \overline{Z}})^2+2(\frac{\overline{U}}{\overline{R}})^2+(\frac{\partial \overline{U}}{\partial \overline{Z}}+\frac{\partial \overline{W}}{\partial \overline{R}})^2] \tag{12}$$

Where $\overline{T_0}$ is the temperature of the inner tube, $\overline{U}$ and $\overline{V}$ are the velocity component in radial and axial directions, the flow is obtained by a sinusoidal wave train which move with a constant speed c along the wall of the tube, wall equation of the tube in the fixed system is given by

$$\overline{R}=H(\overline{Z},t)=a+a\varepsilon Sin\frac{2\pi}{\lambda}(\overline{Z}-ct) \tag{13}$$

Where a radius of the tube, λ wavelength, c wave speed, ε cilia length, and t time. The equation of the cilia tips given mathematically in the form.

$$\overline{Z}=Z_0+\alpha\varepsilon a Sin\frac{2\pi}{\lambda}(\overline{Z}-ct) \tag{14}$$

Where α is the measure of the eccentricity of the elliptic motion of the cilia and Z_0 is a reference position of the cilia. The transformations between the two coordinate systems are

$$\overline{r}=\overline{R},\ \ \overline{z}=\overline{Z}-ct,\ \ \overline{u}=\overline{U},\ \ \overline{w}=\overline{W}-c,\ \ \overline{p}=\overline{P} \tag{15}$$

Where $\left(\overline{u},\overline{w}\right)$ and $\left(\overline{U},\overline{W}\right)$ represent the velocity components of the moving and fixed frame.

The boundary conditions are given by

$$\left.\begin{array}{llll}\dfrac{\partial \overline{W}}{\partial \overline{R}}=0 & ,\dfrac{\partial \overline{T}}{\partial \overline{R}}=0 & at & \overline{R}=0\\ \overline{W}=\dfrac{-2\pi\varepsilon a\alpha c}{\lambda}\cos\dfrac{2\pi}{\lambda}\left(\overline{Z}-c\overline{t}\right) & ,\overline{T}=T_0 & at & \overline{R}=H\end{array}\right\} \tag{16}$$

The thermo-physical properties can be written as:

$$\begin{aligned}&\mu_{nf}=\frac{\mu_f}{\left(1-\varphi\right)^{2.5}},\ \ \rho_{nf}=\left(1-\varphi\right)\rho_f+\varphi\rho_s,\ \ \alpha_{nf}=\frac{K_{nf}}{\left(\rho c_p\right)_{nf}},\\ &\left(\rho B\right)_{nf}=\left(1-\varphi\right)\left(\rho B\right)_f+\varphi\left(\rho B\right)_s,\ \ \left(\rho c_p\right)_{nf}=\left(1-\varphi\right)\left(\rho c_p\right)_f+\varphi\left(\rho c_p\right)_s\\ &\frac{K_{nf}}{K_f}=\frac{\left(K_s+2K_f\right)-2\varphi\left(K_f-K_s\right)}{\left(K_s+2K_f\right)+\varphi\left(K_f-K_s\right)}\end{aligned} \tag{17}$$

Where $\rho_f,\mu_f,B_f,\left(\rho c_p\right)_f$ and K_f are the density, viscosity, the thermal expansion coefficient, the effective heat capacitance and the thermal conductivity of the fluid. While $\mu_s,B_s,\rho_s,\left(\rho c_p\right)_s$ and K_s are the viscosity, the thermal expansion coefficient, the density, the effective heat capacitance and the thermal conductivity of the solid particle.

The dimensionless parameter is given by

$$\left.\begin{array}{l} r=\dfrac{\bar{r}}{a}, \;, \; z=\dfrac{\bar{z}}{a}, \quad u=\dfrac{\bar{u}}{c\delta},, \qquad w=\dfrac{\bar{w}}{c}, \; R_e=\dfrac{\rho_f ca}{\mu_f}, \\ h=\dfrac{H}{a}=1+\varepsilon\cos 2\pi z, \; S_{ij}=\dfrac{a}{\mu_f c}\bar{S}_{ij,} \; p=\dfrac{a^2\bar{p}}{\mu_f c\lambda} \\ Q=\dfrac{Q_0 a^2}{(T_1-T_0)K_f} \; \delta=\dfrac{a}{\lambda}, \; t=\dfrac{c}{\lambda}\bar{t}, \; \theta=\dfrac{\bar{T}-T}{T_1-T_0}, \; G_r=\dfrac{g\rho_f B_f a^2(T_1-T_0)}{\mu_f c} \end{array}\right\} \tag{18}$$

Substitute from equations (15) and (16) in equations (8) to (11) and (16), with apply the approximation long-wavelength $\delta\langle\langle 1$ and small Reynolds number $R_e\langle\langle 1$, we get

$$0=\frac{\partial p}{\partial r}, \tag{19}$$

$$0=-\frac{\partial p}{\partial z}+\frac{\mu_{nf}}{\mu_f}\frac{1}{r}\frac{\partial}{\partial r}(r((1+K_1)\frac{\partial w}{\partial r}-K_2(\frac{\partial w}{\partial r})^3))+\frac{(\rho\beta)_{nf}}{(\rho\beta)_f}G_r\theta, \tag{20}$$

$$0=\frac{K_{nf}}{K_f}\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial\theta}{\partial r})+Q\frac{(\rho c_p)_{nf}}{(\rho c_p)_f} \tag{21}$$

and the boundary conditions in dimensionless form are

$$\left.\begin{array}{llll} \dfrac{\partial w}{\partial r}=0 \quad , & \dfrac{\partial\theta}{\partial r}=0 & at & r=0 \\ w=-1-2\pi\alpha\varepsilon\delta\cos(2\pi z)=k_0 \quad , & \theta=1 & at & r=h \end{array}\right\} \tag{22}$$

Where $K_1=\dfrac{1}{\beta\mu_{nf}d}$, $K_2=\dfrac{K_1}{6a^2d^3}$ are the first and second parameters of Eyring-Powell.

4. Method of Solution

The exact solution of the equation (21) by using equation (22) is written as

$$\theta(r,z)=1+\frac{\lambda_1}{4}(h-r)(h+r) \tag{23}$$

Equation (20) can be simplified by assuming that

$$w(r,z)=w_0+\lambda_2 w_1 \tag{24}$$

By use equations (22)-(24) to solve equation (20) we get

$$\begin{aligned} w(r,z)=&\frac{1}{64}(64k_0+(h-r)(h+r)((16+(3h^2-r^2)\lambda_1)\lambda_2-16\lambda_3)+ \\ &\frac{K_2}{81920(1+K_1)}((2560(h^4-r^4)+640(2h^3-3h^2r^4+r^6)\lambda_1+20(11h^8-24h^4r^4+ \\ &16h^2r^6-3r^8)\lambda_1^2+(13h^{10}-40h^6r^4+40h^4r^6-15h^2r^8+2r^{10})\lambda_1^3)\lambda_2^3- \\ &20(384(h^4-r^4)+64(2h^6-3h^2r^4+r^6)\lambda_1+(11h^8-24h^4r^4+16h^2r^6- \\ &3r^8)\lambda_1^2)\lambda_2^2\lambda_3+640(12(h^4-r^4)+(2h^6-3h^2r^4+r^6)\lambda_1)\lambda_2\lambda_3^2+2560\lambda_3^3(r^4-h^4)) \end{aligned} \tag{25}$$

Where

$$\lambda_1 = \frac{QK_f\left(\rho c_p\right)_{nf}}{K_{nf}\left(\rho c_p\right)_f}, \quad \lambda_2 = \frac{G_r\left(1-\varphi\right)^{2.5}\left(\rho B\right)_{nf}}{\left(\rho B\right)_f\left(1+K_1\right)}, \quad \lambda_3 = \frac{\left(1-\varphi\right)^{2.5}}{\left(1+K_1\right)}\frac{\partial p}{\partial z}. \tag{26}$$

5. Results and Discussion

This article discussed the binary Powell- Eyring Nanofluid of peristaltic flow with heat transfer in a ciliated tube. We investigate the effect of various physical parameters as Grashof number (G_r), volume fraction of the Nanoparticle (ϕ), heat source or Sink parameter (Q), Cilia length (ε) and the first and second parameters of Eyring-Powell (K_1 and K_2) on the velocity $w(r,z)$ and the temperature $\theta(r,z)$. The results are calculated and illustrated in Figures 2-10. We note that Figures 2. and 3. Illustrate the influence of Grashof number G_r and the volume fraction of the Nanoparticle ϕ respectively on the velocity profiles $w(r,z)$, it is noticed that the velocity increase in the interval $r \in [0,1.1]$ then decreases for $r \rangle 1.1$. The effect of the Sink parameter (heat source) Q on the velocity $w(r,z)$ is given in Figure 4. We note that the velocity increase and decrease in a different interval with an increase of heat source Q. Figure 5. indicate that the velocity $w(r,z)$ increases when the cilia length ε increases. From Figure 6. the increase of the first Eyring-Powell parameter K_1 causes an increase in the velocity $w(r,z)$. Figure 7. Represent the effects of the second parameters of Eyring-Powell K_2 on the velocity parameter $w(r,z)$, we note that the velocity $w(r,z)$ decrease with increases of K_2. The temperature $\theta(r,z)$ at various values of heat source Q is shown in Figure 8. We observe that The temperature $\theta(r,z)$ increases when heat source Q increases in the range $0 \le r \le 1.2$ then decreases at $r \rangle 1.2$. Figure 9. shows that the temperature $\theta(r,z)$ decreases with the increases of Nanoparticle ϕ in the interval $0 \le r \le 1.2$ then increases when $r \rangle 1.2$. The depending of temperature $\theta(r,z)$ on the cilia length ε is shown in Figure 10. We note that the temperature $\theta(r,z)$ increases with increasing ε.

6. Conclusion

The binary Powell- Eyring Nanofluid of peristaltic flow with heat transfer in the ciliated tube is investigated. In this study, we consider the approximation of long wavelength and low Renolds number. We solve the partial differential equations which govern the motion by using the appropriate boundary conditions. The differential equations solved by using perturbation equations. We discuss the effect of physical parameters on the flow, as Grashof number (G_r), the volume fraction of the Nanoparticle (ϕ), heat source or Sink parameter (Q), Cilia length (ε), and the first and second parameters of Eyring-Powell (K_1 and K_2) which illustrated graphically through a set of Figures. It is found that the Grashof number G_r, the volume fraction of the Nanoparticle ϕ, the Cilia length ε and the first Eyring-Powell parameters K_1 play an important role for increasing the velocity parameter where the increase of G_r, ϕ, ε and K_1 give increases in the velocity $w(r,z)$ in the interval $r \in [0,1.1]$ then decrease in the interval $r \rangle 1.1$. The second Eyring-Powell parameters K_2 cause a decrease in the velocity $w(r,z)$. The temperature $\theta(r,z)$ increases with the increases of Sink parameter Q in the interval $r \in [0,1.2]$ and then decreases for $r \rangle 1.2$. The increase of the volume fraction of the Nanoparticle ϕ gives a decrease in $\theta(r,z)$ in the interval $r \in [0,1.2]$ then an increase in the interval $r \rangle 1.2$. The temperature $\theta(r,z)$ increase with the increases of the cilia length parameter ε.

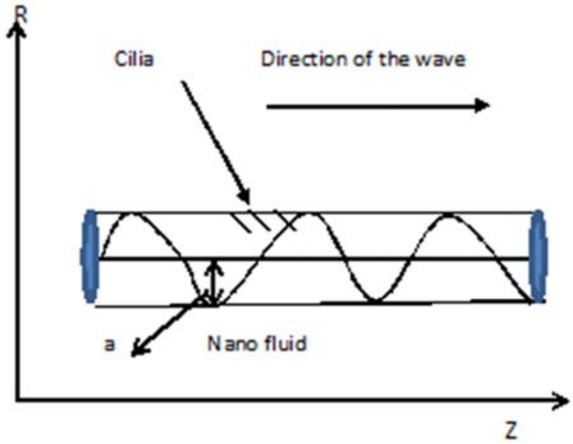

Figure 1. *The geometry of the problem.*

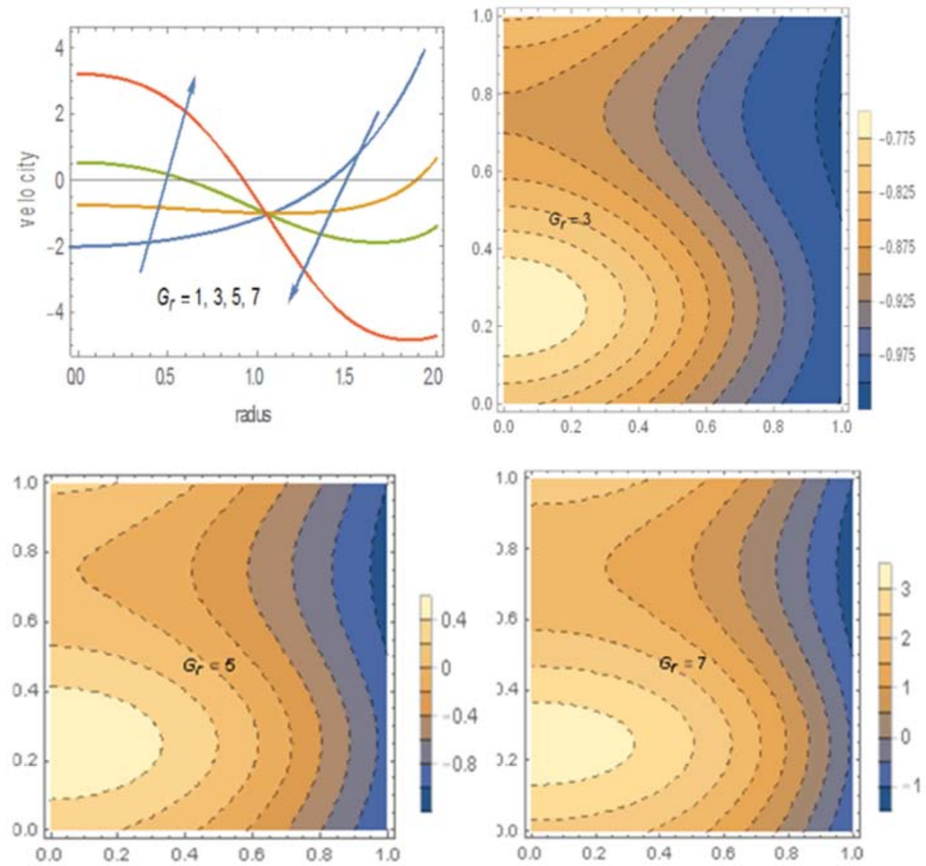

Figure 2. *The relation between the velocity and the Grashof Number* G_r *where* $K_1 = 1.2, K_2 = 0.3, z = 0.3, Q = 3, \varepsilon = 0.05, \alpha = 0.02, \delta = 0.11, \varphi = 0.02$.

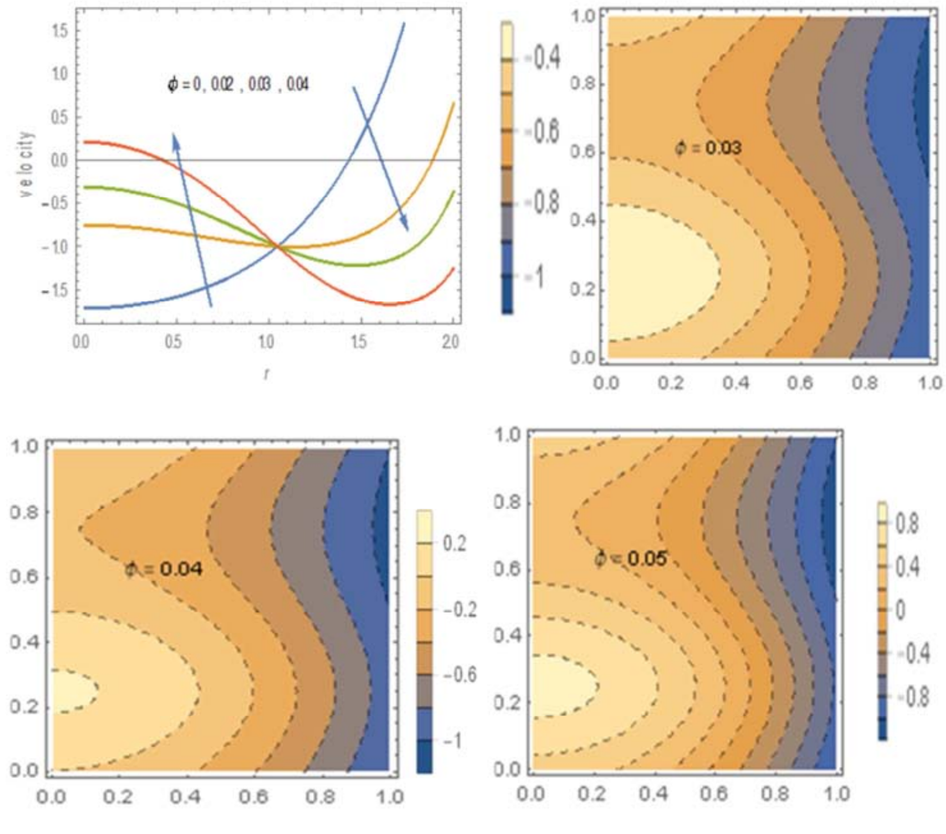

Figure 3. *The relation between the velocity and the Nanoparticle* φ *where* $K_1 = 1.2, K_2 = 0.3, z = 0.3, Q = 3, \varepsilon = 0.05, \alpha = 0.02, \delta = 0.11, G_r = 3$.

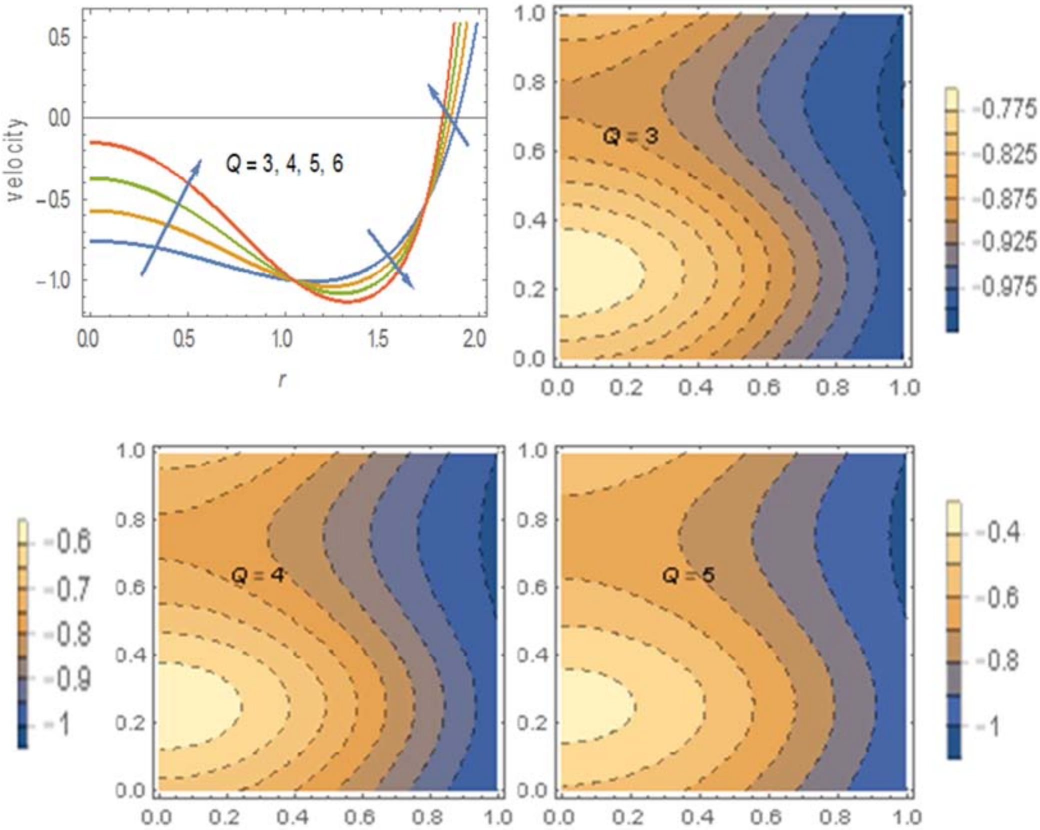

Figure 4. *The relation between the velocity and the Sink parameter* Q *where* $K_1 = 1.2, K_2 = 0.3, z = 0.3, G_r = 3, \varepsilon = 0.05, \alpha = 0.02, \delta = 0.11, \varphi = 0.02$.

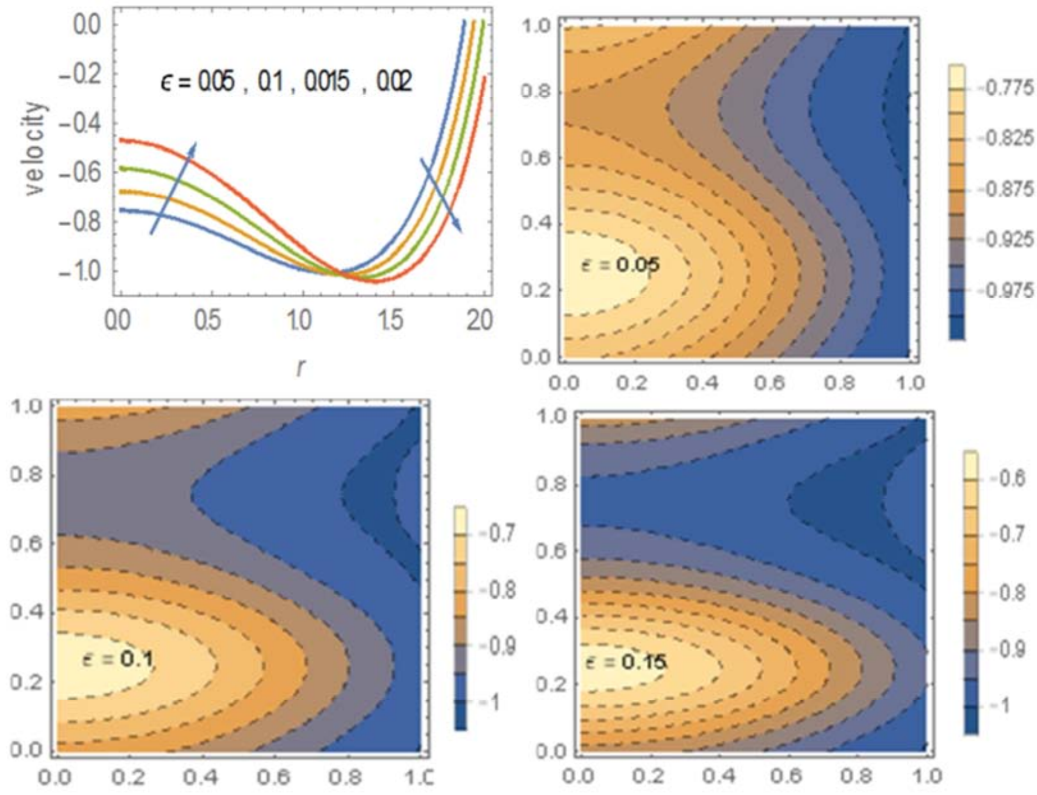

Figure 5. *The relation between the velocity and the cilia length* ε *, where* $K_1 = 1.2, K_2 = 0.3, z = 0.3, Q = 3, G_r = 3, \alpha = 0.02, \delta = 0.11, \varphi = 0.02$.

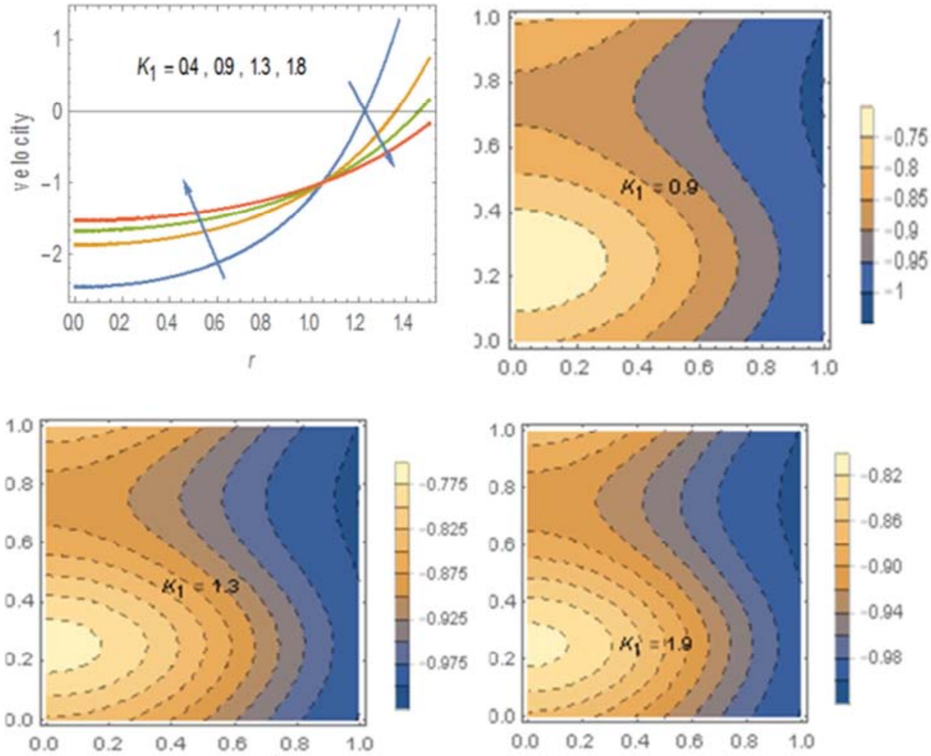

Figure 6. *The relation between the velocity and the first parameter of Eyring-powell* K_1 *where* $G_r = 3, K_2 = 0.3, z = 0.3, Q = 3, \varepsilon = 0.05, \alpha = 0.02, \delta = 0.11, \varphi = 0.02$.

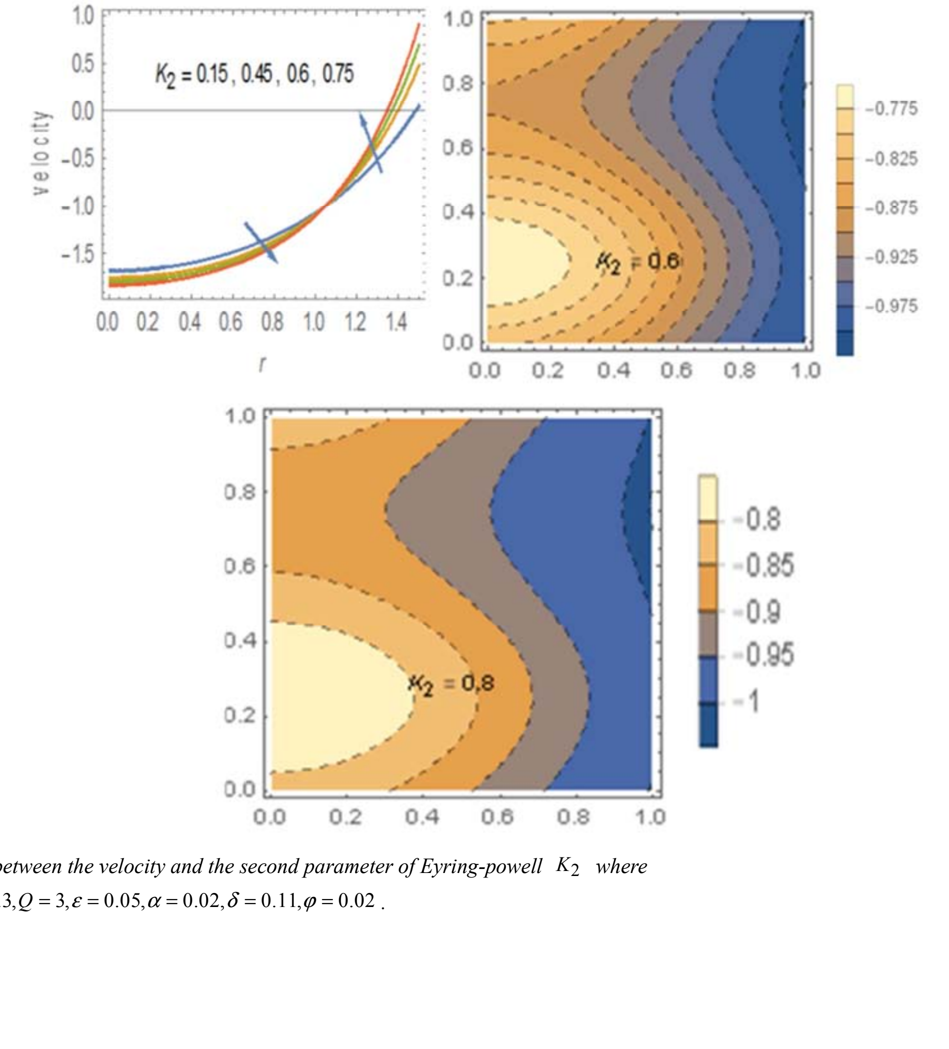

Figure 7. *The relation between the velocity and the second parameter of Eyring-powell* K_2 *where* $K_1 = 1.2, G_r = 0.3, z = 0.3, Q = 3, \varepsilon = 0.05, \alpha = 0.02, \delta = 0.11, \varphi = 0.02$.

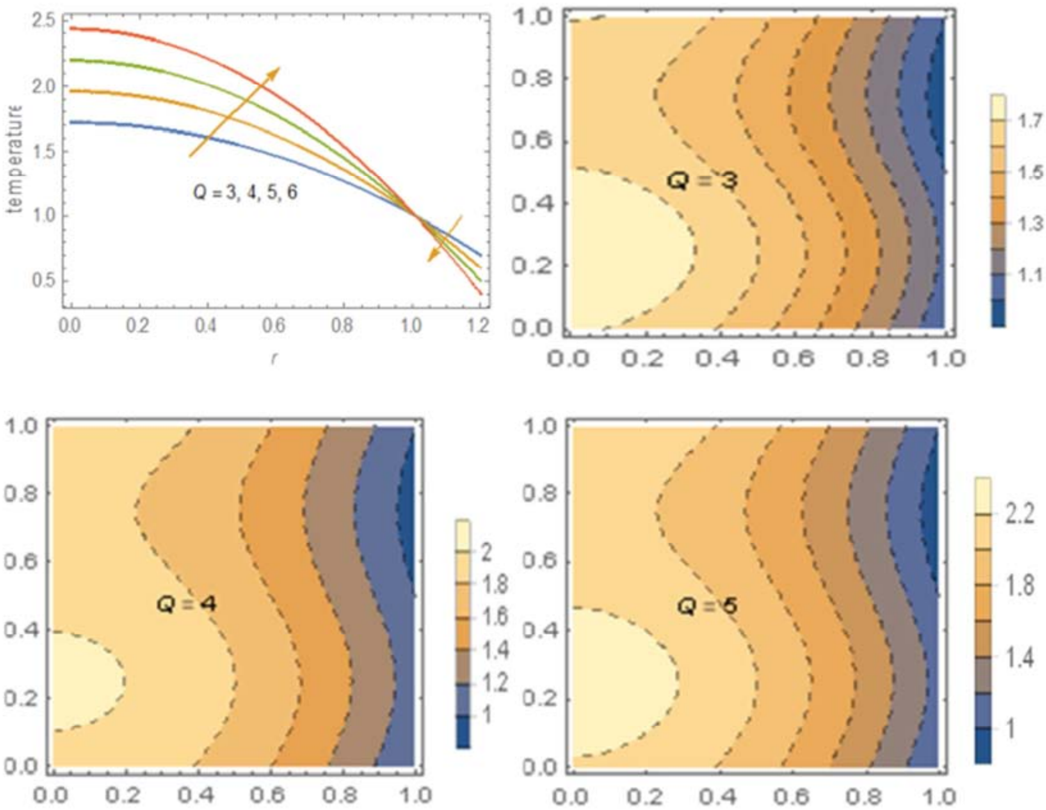

Figure 8. *The relation between the temperature and the Sink parameter Q where* $z = 0.3, \varepsilon = 0.05, \varphi = 0.02$.

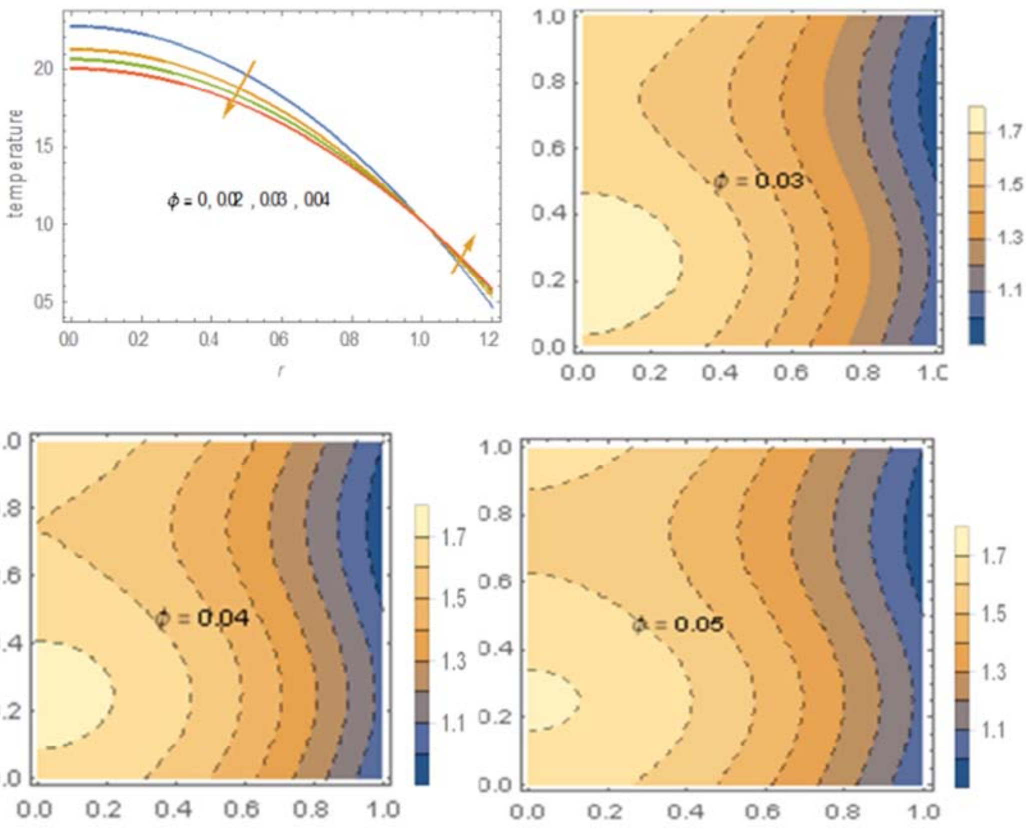

Figure 9. *The relation between the temperature and the Nanoparticle* φ *where* $z = 0.3, Q = 3, \varepsilon = 0.05$.

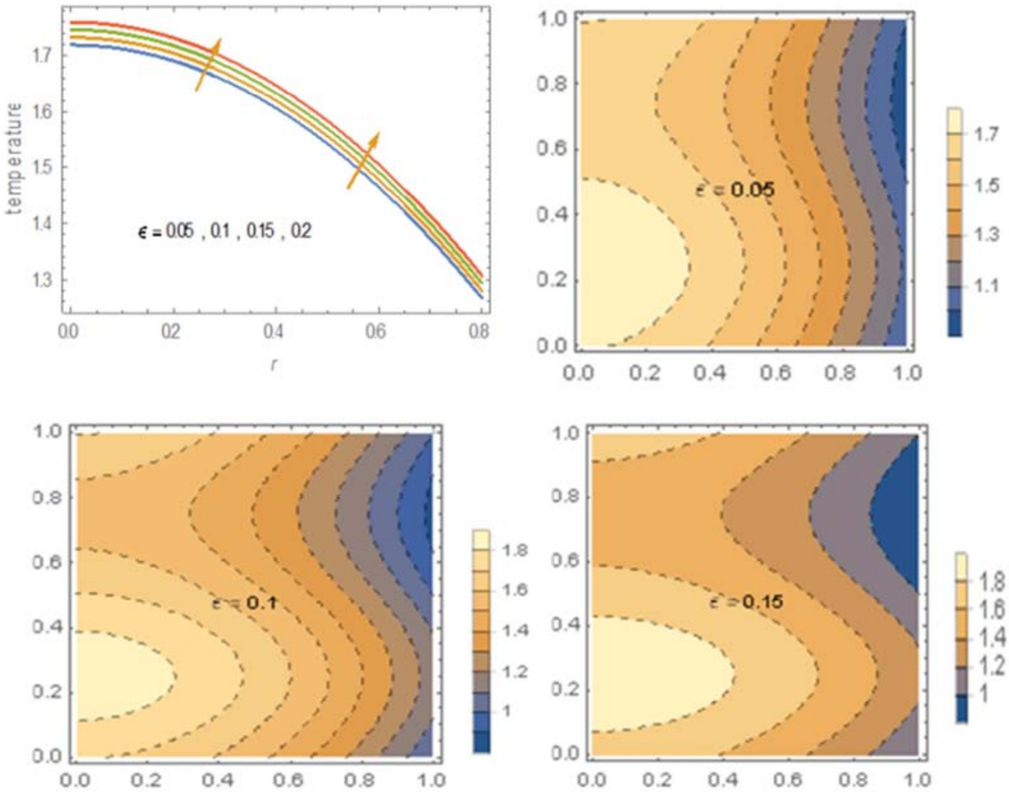

Figure 10. *The relation between the temperature and the cilia length* ε *, where* $z = 0.3, Q = 3, \varphi = 0.02$.

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