International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

# Effect of Heat Source on the Rotatory Flow Past an Accelerated Infinite Vertical Plate through Porous Medium

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**Submitted:** 13/08/2024 **Revised:** 23/09/2024 **Accepted:** 02/10/2024

**Abstract:** The precise solution to the unstable free convection flow of a viscous incompressible fluid past an accelerating infinite vertical plate via a porous medium in the presence of heat source has been developed using the Laplace transform technique. The permeability parameter λ, Prandtl number Pr, the effects of rotation parameter Rc in presence of heat source S on axial and transverse velocities are the main topics of this investigation of fluid dynamics in porous media for air and water.The rotating parameter for water, axial velocity increases with Rc whereas transverse velocity decreases. The Permeability parameter λ oscillates with axial velocity but transverse velocity decreases, as λ rises. For air, axial velocity becomes unstable as Rc decreases and λ increases. A lower axial velocity is the result of the Prandtl number pr. As Rc decreases, the axial velocity for both air and water becomes unstable. As time t rises, water's axial velocity also increases. The flow of water and air is destabilized by heat source S.For water; Axial and transverse skin friction decrease with Rc increases. Axial and transverse skin friction oscillates for air as Rc increases. Axial skin friction for both media decrease with increasing time t. Transverse skin friction falls in air as well as in water. Axial skin friction decreases for water as λ increases, but it is irregular for air. Skin friction oscillates for both mediums due to heat source S. In this paper, study effect of different parameters on the viscous fluid in presence of Heat source.

***Keywords:*** *Natural convection, Heat transfer, Coriolis force, Heat source, Porous medium*

## Introduction

Because fluid dynamics has many applications in both engineering and natural phenomena, it is still a basic field of research, especially when it comes to flow past vertical surfaces. Stokes [1] laid the foundation for understanding complex fluid behaviour completely by presenting the first exact solution of the Navier-Stokes equation for viscous incompressible fluid flow past an infinite horizontal impulsively started plate. This work is the main source of seeds for subsequent development. Numerous studies examining different aspect of fluid flow, particularly in relation to natural convection and heat transmission, have been cause to start these new findings for vertical plates.

According to a large body of research and in-depth debates in heat transfer textbooks, scholars have paid close attention to the natural convection flow of viscous incompressible fluid past infinite vertical plates (Gebhart, [2]; Bejan, [3]). The consequences of impulsive motion on an isothermal vertical plate surrounded by a motionless fluid mass make the phenomena much more fascinating. By studying free convection currents close to such plates using the Laplace transform approach, Soundelgeker [4] significantly advanced our knowledge of this.

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Over the past three decades, the study of convective heat transfer through porous media has been a critical area of research due to its growing industrial significance. This interest is a result of developing technology in several areas, such as nuclear reactors, gas-cooled electronics equipment, and porous insulation. The practical uses include increased oil recovery, drying porous materials like wheat, and storing things that produce heat, such as coal and grains. The importance of the discipline is especially clear in reservoir engineering, where improving the recovery of water and oil from underground sources requires an understanding of fluid flow through porous media.

The Darcy flow model served as the primary foundation for early studies on porous medium flow. But Brikman's [5] revision, which more accurately explained very viscous flow through extremely permeable porous surfaces, was a breakthrough. Numerous review papers on natural convection across porous media have established the importance of this adjustment in understanding completely the increasingly complicated flow situations. (Cheng, [6]; O'Sullivan, [7]; Bejan, [3]).

The study of fluid flow becomes even more difficult when rotation effects are considered. The Earth's rotation, a phenomenon that is almost universal, affects fluid flow in numerous geophysical applications. Gustave-Gaspard Coriolis laid the mathematical groundwork for grasping these phenomena in 1835 [8], and his contributions remain essential to meteorological research today. Proudman's [9] discovery of Coriolis force dominance in steady flow and the well-known Ekman [10] flow, which was driven by Coriolis forces, have greatly advanced our knowledge of rotating fluid systems.

The outcome of mass transfer in spinning fluid systems have been the subject of recent expansions. Experimental research on the effect of rotating Coriolis force on mass transfer distribution was done by Park and Lau [11] and Han et al. [12]. By investigating the results of mass transfer on transient flow past an infinite vertical plate in a rotating fluid, Bhalerao and Lahurikar [13] made significant progress in this area. Only a small number of investigations have been conducted on isothermal flow in rotating porous media. (Vadasz, [14]; Bejan, [15]). Investigation is made possible by the added complications that arise when heat sources are included into such systems. The importance of heat source impacts in different flow configurations has been shown in recent research. Considering thermal diffusion and diffusion thermo effects, Srinivasa Raju et al. [16] examined the effects of heat sources and thermal radiation on unsteady MHD free convection flow across an infinite vertical plate in a porous material. Their research made clear how important heat sources are in altering flow properties and heat transfer rates. The flow field becomes much more complicated due to the accelerated motion of vertical plate. The interplay between accelerated plate motion and free convection currents greatly affects flow behaviour, as demonstrated by Soundalgekar and Gupta [17], who used the Laplace-transform approach to achieve accurate answers. The flow past an accelerating infinite plate as affected by heat sources and mass transfer studied by Lahurikar, Pohanerkar, and Soundalgekar [18]. Lahurikar, Gitte, and Ubale Patil [19] investigated the effect of mass transfer on flow through a porous media past an infinite vertical plate that was begun impulsively in a rotating fluid. The impact of mass transfer effects on the Stokes problem for a rotating fluid with an infinite vertical plate studied by Gitte, Ubale Patil, and Lahurikar [20].

This generates a complicated system that must be carefully analysed to understand completely the underlying physics and possible applications when coupled with heat sources and rotating effects in a porous material in absence of mass concentration. By examining the combined impacts of heat sources on rotatory flow past an accelerated infinite vertical plate through a porous material, the current work seeks to close a large gap in the body of previous knowledge in absenteeism of concentration. The lack of knowledge about how heat sources affect flow properties in rotating porous systems, especially when plate motion is accelerated rather than impulsive, is what encourage this study. The study is applicable to several industrial settings where heat production and rotational effects together in porous structures, such as heat exchangers, chemical processing machinery, and geothermal systems.

Our research uses a careful and complete mathematical methodology, obtaining precise solutions to the governing equations by the application of the Laplace transform technique. We may investigate the separate and combined impacts of several factors, such as rotation rate, porosity, heat source strength, and plate acceleration, on the flow field and heat transfer properties using this analytical method. The investigation's findings will advance our knowledge of complex fluid dynamics in rotating porous systems and offer clear and deep information for engineering applications where rotation effects and heat production are important factors. By include the impacts of heat sources in a rotating porous medium a combination that has not been thoroughly investigated in the setting of rapid plate motion this study expands and improves upon another research in the subject.

The results will contribute to the theoretical understanding of complex fluid flow phenomena and have important outcome for the design and optimization of industrial operations involving heat transfer in rotating porous systems**.**

## MATHEMATICAL ANALYSIS

With X'-axis vertically upward along the accelerating plate, Y'- horizontally perpendicular to X'-axis, and Z'- axis normal to the X'-Y' plane, we consider an infinite vertical plate submerge in a porous material surrounded by a viscous incompressible system.

The fluid and plate are initially immobile and have a constant starting temperature ($T'_\infty$). The porous medium is stable. The plate experiences uniform acceleration in a vertical direction when t'>0, and its temperature rises to a constant ($T'_w$) at the same time. With an angular velocity of Ω', the fluid begins to move very slowly along the Z' axis. Except for the physical variables, which are all functions of Z' and t', the plate is infinite. A fluid in a porous material has a uniform distribution, is viscous, and is incompressible. The fluid's angular velocity (Ω') is constant. Coriolis forces resist fluid element displacement and right angles to both rotational axes when fluid travels gradually due to earth's rotation. The square and higher order rotational components in the centrifugal forces may be ignored if the system is spinning extremely slowly. Centrifugal forces act on a fluid when it rotates slowly. Heat sources are pooled and inertia effects are negligible since the plate is limitless in area and with absence of concentration. The following set of equations, which disregard the Sorate-Dufur effect and viscous dissipation heat, can then be used to show that the flow is regulated under conventional Boussinesq's approximation (Gebhart and Pera, [21]).

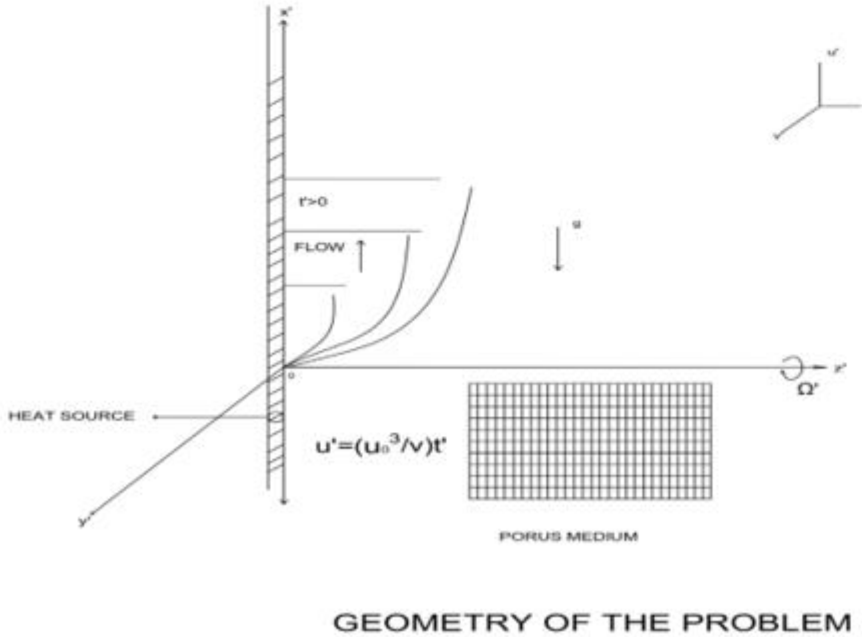



**Figure 1:- Physical Significance**

In accordance with Gebhart and Pera [21], we can demonstrate that a set of linked partial differential equations governs the unstable free convection flow under standard Boussinesq's approximations:

$$\frac{\partial u'}{\partial t'} - 2\Omega' v' = g\beta(T' - T'_\infty) + \nu \frac{\partial^2 u'}{\partial z'^2} - \frac{\nu}{\kappa} u' \qquad 1.$$

$$\frac{\partial v'}{\partial t'} + 2\Omega' u' = \nu \frac{\partial^2 v'}{\partial z'^2} - \frac{\nu}{\kappa} v' \qquad 2.$$

$$\rho C_P \frac{\partial T'}{\partial t'} = K \frac{\partial^2 T'}{\partial z'^2} + S_1(T' - T'_\infty) \qquad 3.$$

The initial and boundary conditions are

$t' \leq 0, u' = 0, T' = T'_\infty$ for all $Z'$

$t' > 0, u' = \left(\frac{U_0^3}{\nu}\right) t', T' = T'_w$ at $Z'=0$

$u' = 0, T' \to T'_\infty,$ as $Z' \to \infty$ 4.

In this case, u' represents the velocity components of X'. and $v'$ is the velocity component of the Y' axis. g is the acceleration caused by gravity , β is the coefficient of volume expansion, T' is the fluid temperature close to the plate, $\nu$ is the kinematic viscosity, $C_p$ is the specific heat at constant pressure, K is thermal conductivity, $U_o$ is the plate's impulsive velocity, κ is the coefficient of permeability ,which is constant and increases with the ease of percolation; Muskat [22] discusses the conditions under which κ can be taken at constant, and ρ is the density.

On introducing the following nondimensional quantities,

$U=\frac{u'}{U_O}$ , $v=\frac{v'}{U_O}$ , $t=\frac{t'}{\nu}GU_O^2$ , $z=\frac{z'U_O\sqrt{G}}{\nu}$ , $Pr=\frac{\mu C_p}{K}$

$G=\frac{\nu\beta g(T_w'-T_\infty')}{U_o^3}$, $\theta=\frac{(T'-T_\infty')}{(T_w'-T_\infty')}$ ,$Rc=\frac{\Omega'\nu}{GU_O^2}=\frac{1}{GR_OR_e}$ ,$S=S_1\nu^2/kU_o^2$ 5.

$K^*=\frac{\nu}{\kappa U_o^2}$, $\lambda=\frac{K^*}{G}$

G stands for Grashof number, θ for nondimensional temperature, $R_o$ for Rossby number, $R_e$ for Reynolds number, and Rc for coriolis force induced rotational parameter. The porous media parameter, λ, increases with the density of the porous medium.

Equation (1) – (4) reduce to the following nondimensional form

$$\frac{\partial u}{\partial t}-2Rcv=\frac{\partial^2 u}{\partial z^2}+\theta-\lambda u \quad 6.$$

$$\frac{\partial v}{\partial t}+2Rcu=\frac{\partial^2 v}{\partial z^2}-\lambda v \quad 7.$$

$$pr\frac{\partial\theta}{\partial t}=\frac{\partial^2\theta}{\partial z^2}+S\theta \quad 8.$$

The initial and boundary conditions are

$t\leq 0, u=0, \theta=0$ For all Z

$t>0, u=\frac{t}{G}, \theta=1$ as Z=0

$u=0, \theta=0$ as Z→ ∞ 9.

Now we combine (6) and (7) by introducing q= u +i v, which then reduce to

$$\frac{\partial q}{\partial t}+2iRcq=\theta+\frac{\partial^2 q}{\partial z^2}-\lambda q \quad 10.$$

$$Pr\frac{\partial\theta}{\partial t}=\frac{\partial^2\theta}{\partial z^2}+S\theta \quad 11.$$

The initial and the boundary conditions are

$t\leq 0$ ,q = 0,$\theta$ =0 for all z

$t\geq 0$, $q=\frac{t}{G}$, $\theta$ = 1 at z=0

q = 0, $\theta$ = 0 as z→ ∞

Equations 10 and 11 have solutions that fulfil starting and boundary conditions, which are obtained using the standard Laplace transform method.

$$\theta=\frac{1}{2}\{e^{-\sqrt{pr\alpha t}(2\eta)}erfc(\eta\sqrt{pr}-\sqrt{\alpha t})+e^{\sqrt{pr\alpha t}(2\eta)}erfc(\eta\sqrt{pr}+\sqrt{\alpha t})\}$$

$$q=\frac{t}{2G}(e^{-\sqrt{b_1t}(2\eta)}erfc(\eta-\sqrt{b_1t})+e^{\sqrt{b_1t}(2\eta)}erfc(\eta+\sqrt{b_1t})-\frac{\eta\sqrt{t}}{2G\sqrt{b_1}}\{e^{-\sqrt{b_1t}(2\eta)}erfc(\eta-\sqrt{b_1t})+e^{\sqrt{b_1t}(2\eta)}erfc(\eta+\sqrt{b_1t})\}-\frac{1}{2a(pr-1)}\{e^{-\sqrt{b_1t}(2\eta)}erfc(\eta-\sqrt{b_1t})+e^{\sqrt{b_1t}(2\eta)}erfc(\eta+\sqrt{b_1t})\}+\frac{e^{at}}{2a(pr-1)}\{e^{-\sqrt{(a+b_1)t}(2\eta)}erfc(\eta-\sqrt{(a+b_1)t})+\{e^{\sqrt{(a+b_1)t}(2\eta)}erfc(\eta+\sqrt{(a+b_1)t})+\frac{1}{2a(pr-1)}\{e^{-2\eta\sqrt{\alpha tpr}}erfc(\eta\sqrt{pr}-\sqrt{\alpha t})+e^{2\eta\sqrt{\alpha tpr}}erfc(\eta\sqrt{pr}+\sqrt{\alpha t})\}-\frac{e^{at}}{2a(pr-1)}\{e^{-\sqrt{pr(a+\alpha)t}(2\eta)}erfc(\eta\sqrt{pr}-\sqrt{(a+\alpha)t})+e^{\sqrt{pr(a+\alpha)t}(2\eta)}erfc(\eta\sqrt{pr}+\sqrt{(a+\alpha)t})\}$$

Where, $\eta = \frac{z}{2\sqrt{t}}$ , $b_1 = \lambda + 2iRc$ ,a= $\frac{s+b_1}{Pr-1}$

The skin friction is derived in nondimensional form from the velocity field as given below

$2\sqrt{t}\,\tau = -\frac{dq}{d\eta}|\eta = 0 = -(\tau_x + \tau_y)$

Where

$$\tau = \frac{\tau'\sqrt{G}}{\rho U_0} - \frac{dq}{d\eta|_{\eta=0}}$$
$$= \frac{t}{G}\left(-\frac{2}{\sqrt{\pi}}e^{-b_1 t} - 2\sqrt{b_1 t}\; erf\sqrt{b_1 t}\right)$$
$$- \frac{1}{(s+b_1)}\left[-\frac{2}{\sqrt{\pi}}e^{-b_1 t} - 2\sqrt{b_1 t}\; erf\sqrt{b_1 t}\right]$$
$$+ \frac{e^{at}}{(s+b_1)}\left[-\frac{2}{\sqrt{\pi}}e^{-(a+b_1)t} - 2\sqrt{(a+b_1)t}\; erf\sqrt{(a+b_1)t}\right]$$
$$+ \frac{1}{(s+b_1)}\left[-\frac{2}{\sqrt{\pi}}e^{\frac{st}{Pr}} - 2i\sqrt{st}\left(i\sqrt{\frac{st}{Pr}}\right)\right.$$
$$\left.- \frac{e^{at}}{(s+b_1)}\left[-\frac{2}{\sqrt{\pi}}e^{-(a+\alpha)t} - 2\sqrt{Pr}\sqrt{(a+\alpha)t}\; erf\sqrt{(a+\alpha)t}\right]\right]$$

Where, $b_1 = \lambda + 2iRc$, a= $\frac{s+b_1}{Pr-1}$

We have divided τ into real and imaginary components using Lahurikar's [23] formulae. $\tau_x$ the real part is axial skin friction and $\tau_y$ is imaginary part which is Transverse skin friction. The values of $\tau_x$ and $\tau_y$ that we calculated are shown in table (2) and table (3).

## Result and Discussion:

### 3.1 Results:

In following figures the velocity profiles are shown, in these figures all parameters are held constant except one which is discussed

1)In Figure 2: - Rotating parameter Rc falls as Transverse velocity rises for water.

2)In figure 3: -Axial velocity of water rises as rotating parameter Rc rises for water.

3)In figure 4: - The permeability parameter λ oscillates as axial velocity increases for water.

4)In figure 5: - Permeability parameter λ increases the Transverse velocity decreases, which shows that flow decreases as increase in λ for water.

5) In figure 6: - For air, as rotating parameter Rc decreases the axial velocity exhibits instability.

6) In figure 7: -As the Prandtl number pr increases there is fall in axial velocity i.e. flow slows down.

7)In figure 8: - For air, Permeability parameter λ increases, the axial velocity become irregular.

8)In figure 9 and figure 10: - For air and water both, it is noted that Rc's axial velocity-driven flow is unstable i.e., the axial velocity becomes irregular as Rotating parameter Rc increases.

9)In figure 11: -For water, time t increases axial velocity increases.

10) In figure 12: -Transverse velocity falls as permeability parameter λ uprises in air.

11) In Figure 13 and Figure 14: -The flow becomes unstable as heat source S increases for both air and water.

In figure 5 and figure 12 the drop is larger for high λ when the porous media is denser.

These observations we obtain from tables (1) and (2) of axial and Transverse skin friction:

For water, axial skin friction and Transverse skin friction both decreases for Rotational parameter Rc and for air axial and transverse skin friction both oscillates. As time t increases axial skin friction decreases for both air and water, Transverse skin friction for water decreases and for air increases. For permeability parameter λ, axial skin friction decreases for water and unstable for air where Transverse skin friction rises for water and decreases for air. As value of Heat source S increases, axial and Transverse skin friction oscillates for air and water.

## 3.2 Figures and Tables:

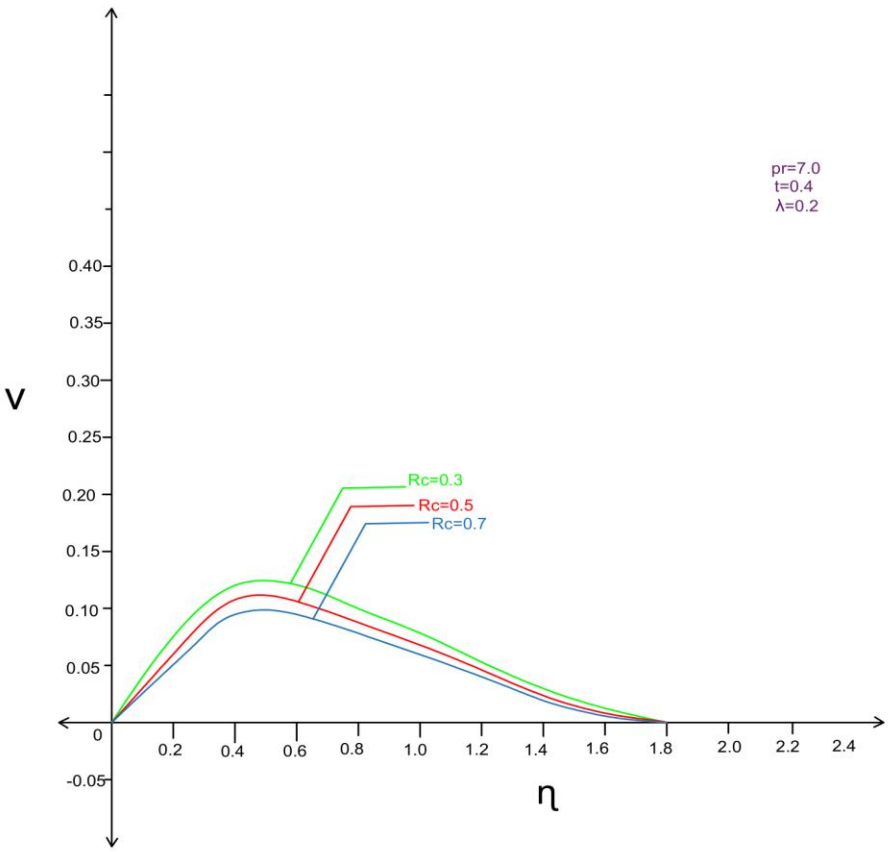



Figure 2: - As Transverse velocity increases, Rc decreases.

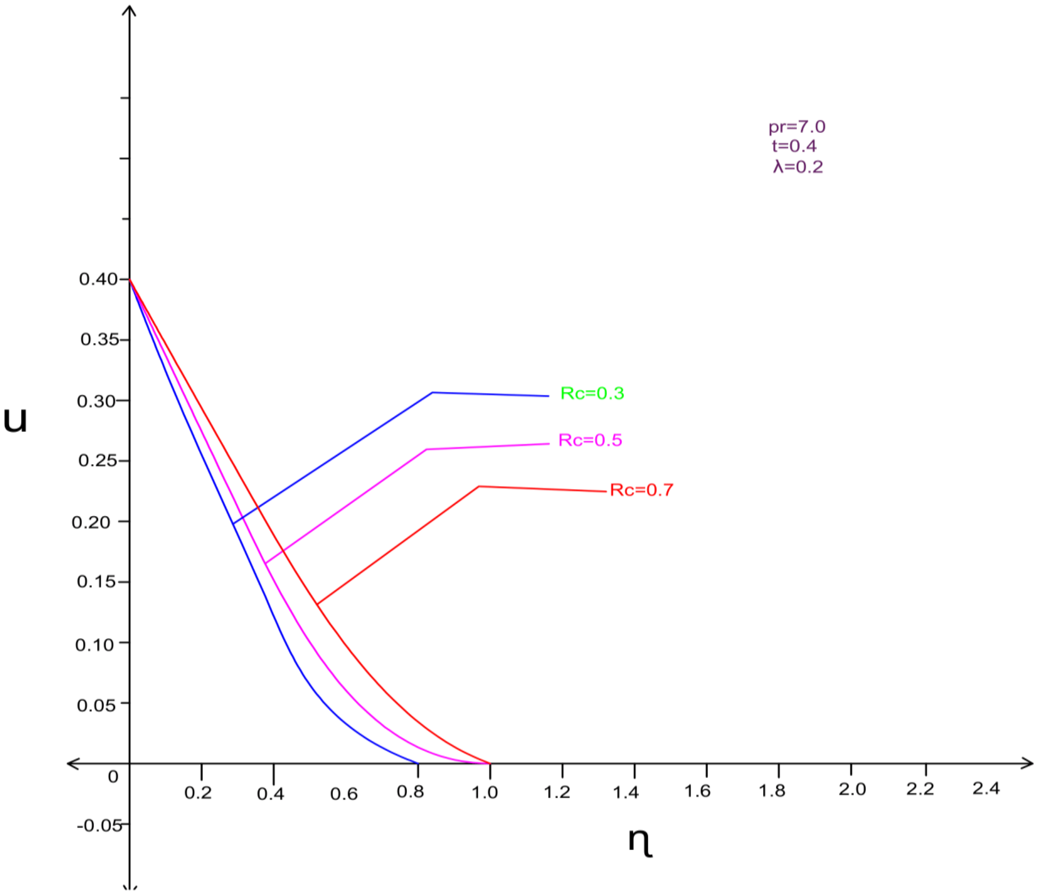



Figure 3:- Rc rises as axial velocity rises

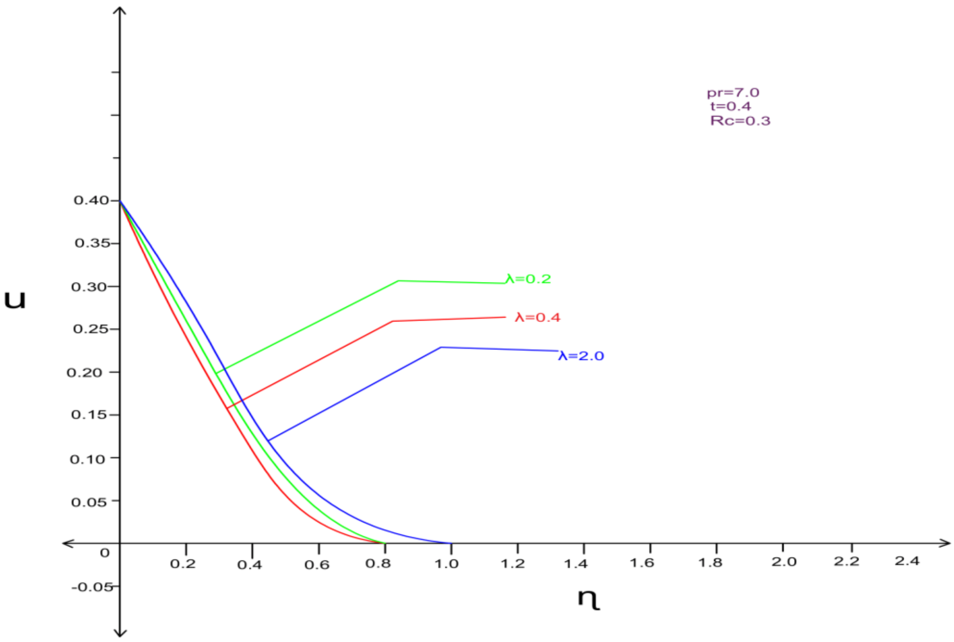
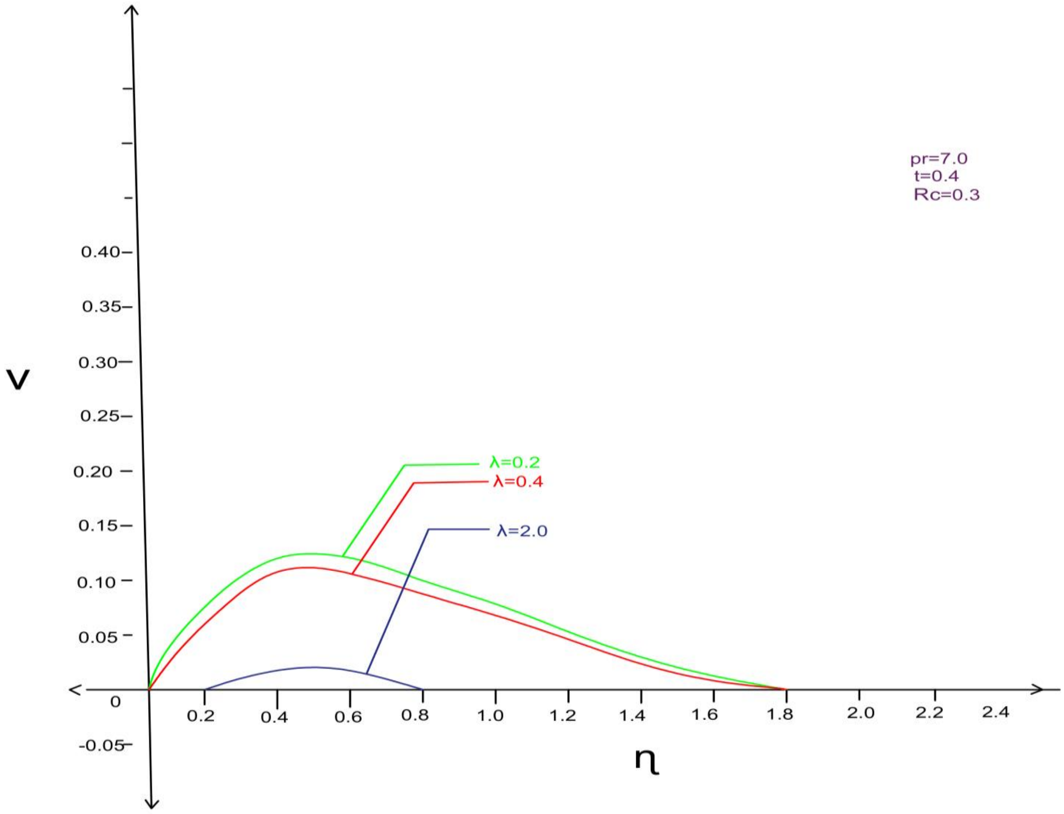



**Figure 4:- As axial velocity increases ,permeability parameter λ oscillates**




**. Fig 5:- As λ increases flow decreases**

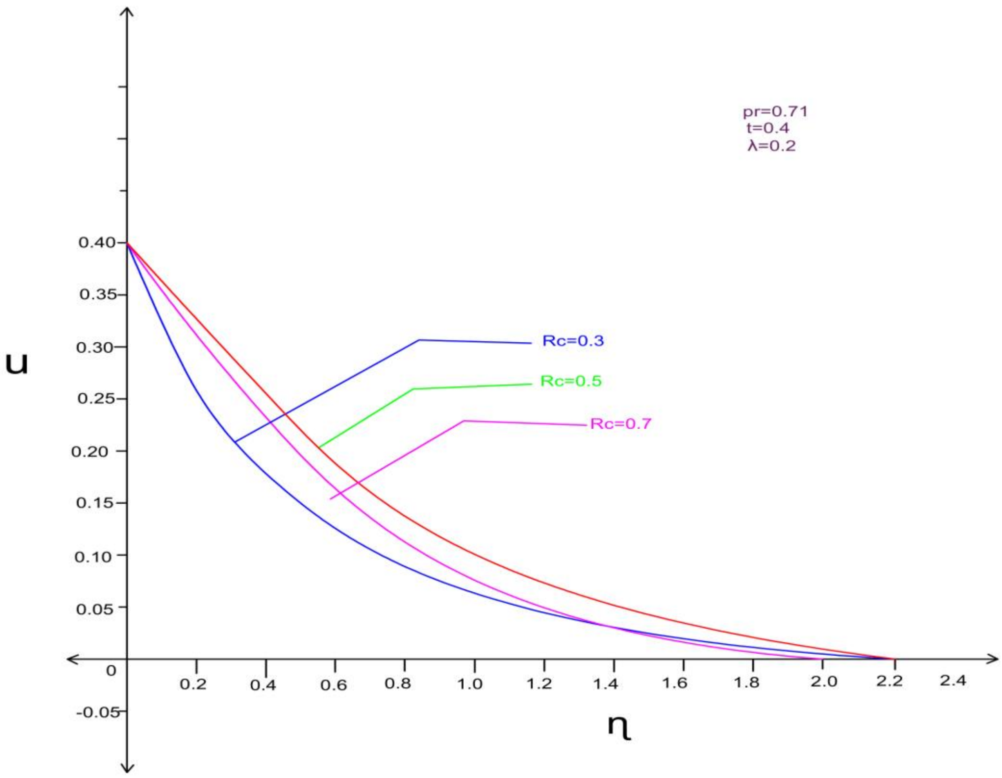



**Fig 6:- The rotating parameter Rc decreases then flow is irregular.**

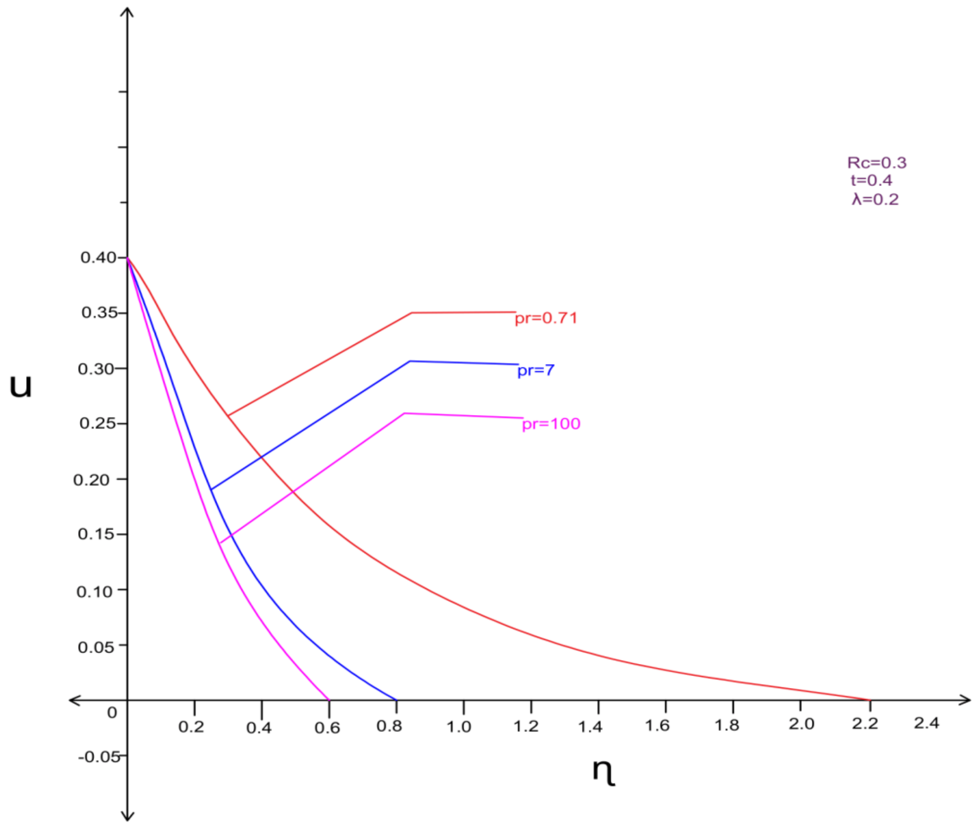



**Fig 7:- As a Prandtl number Pr increases, the flow slows down.**

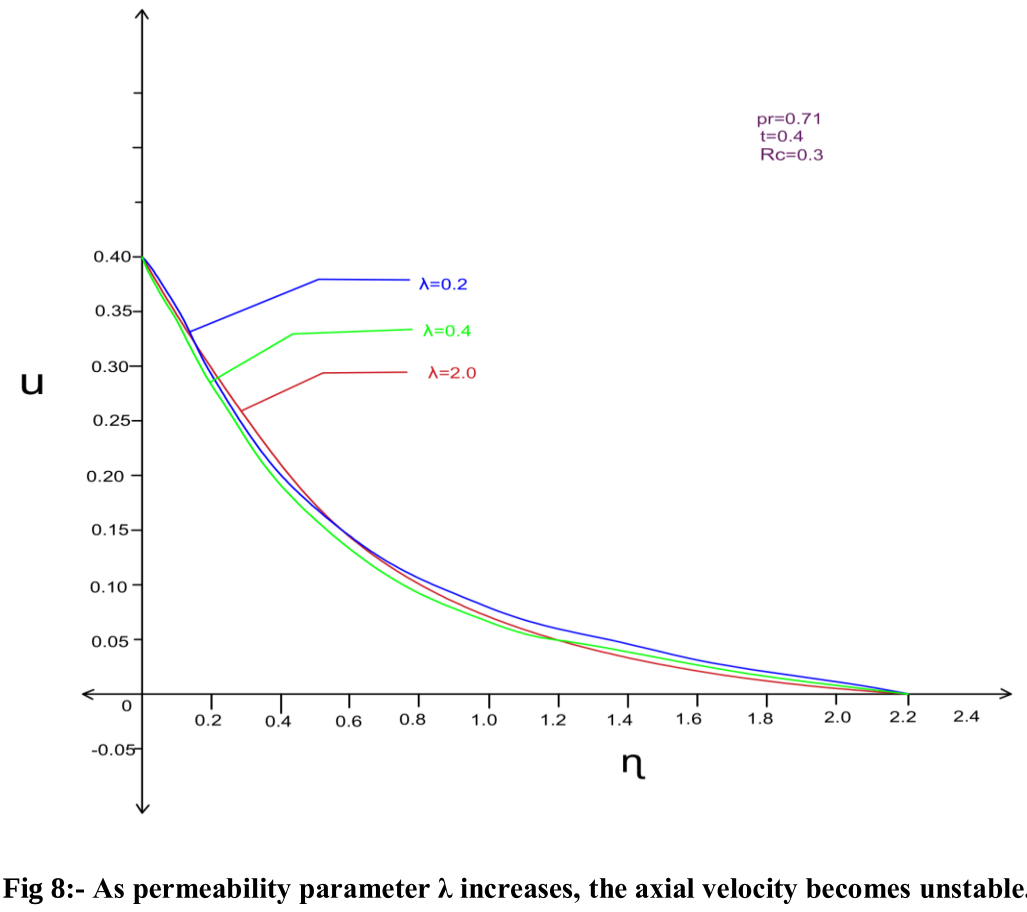



**Fig 8:- As permeability parameter λ increases, the axial velocity becomes unstable.**

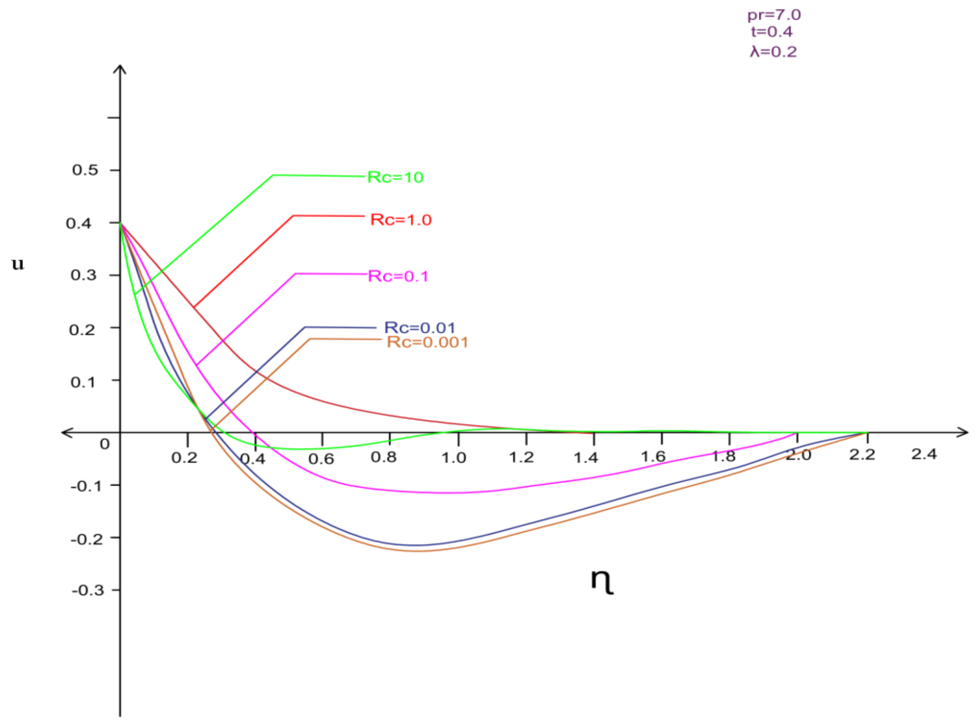



**Fig 9:- The rotating parameter Rc decreases ,then flow become irregular**

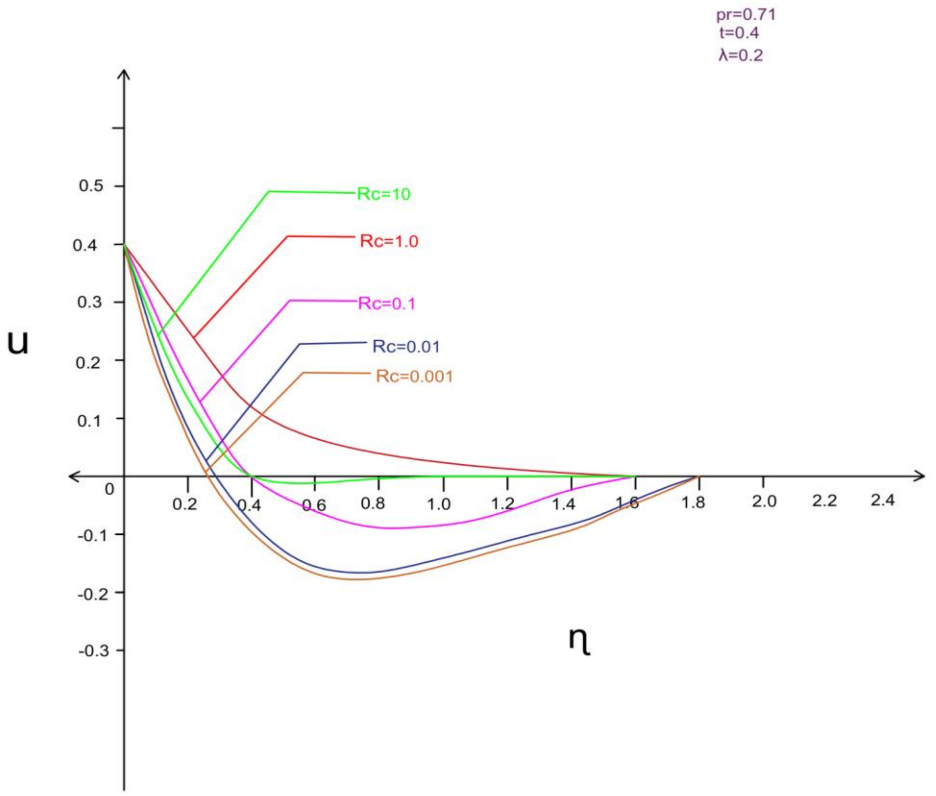



**Figure 10: As Rc increases, axial velocity becomes unstable**

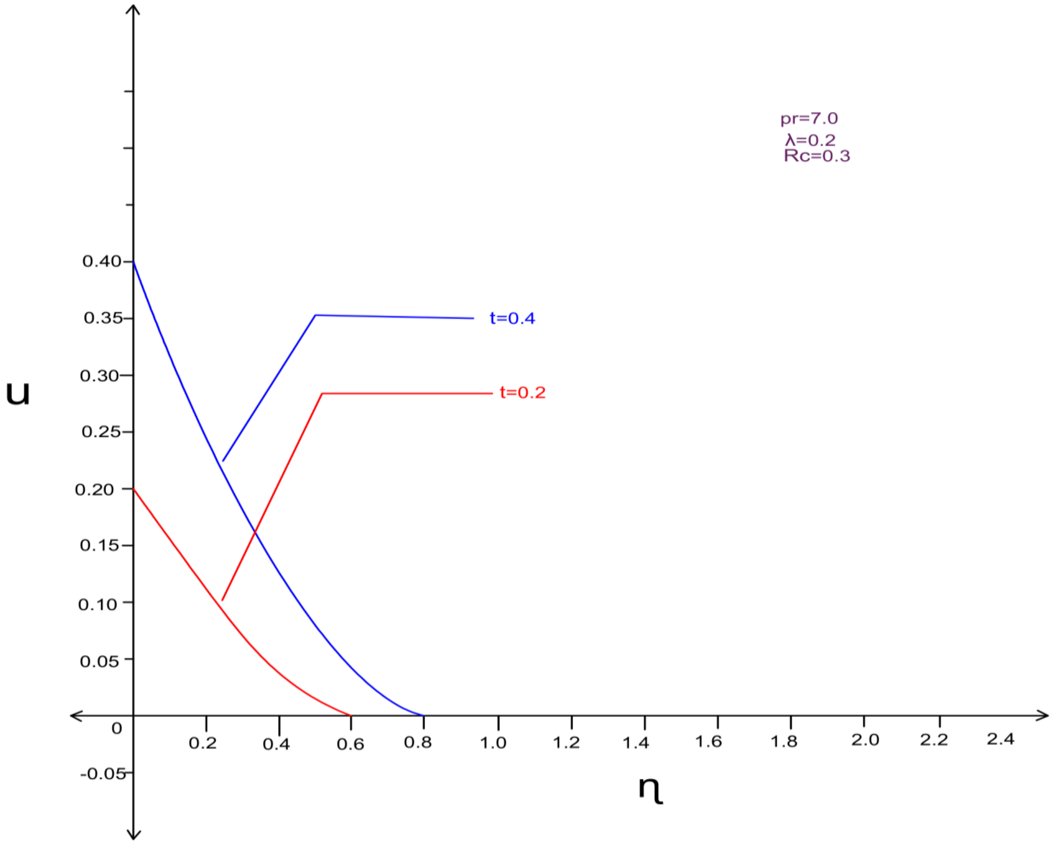



**Fig 11:- As time t rises axial velocity also rises**

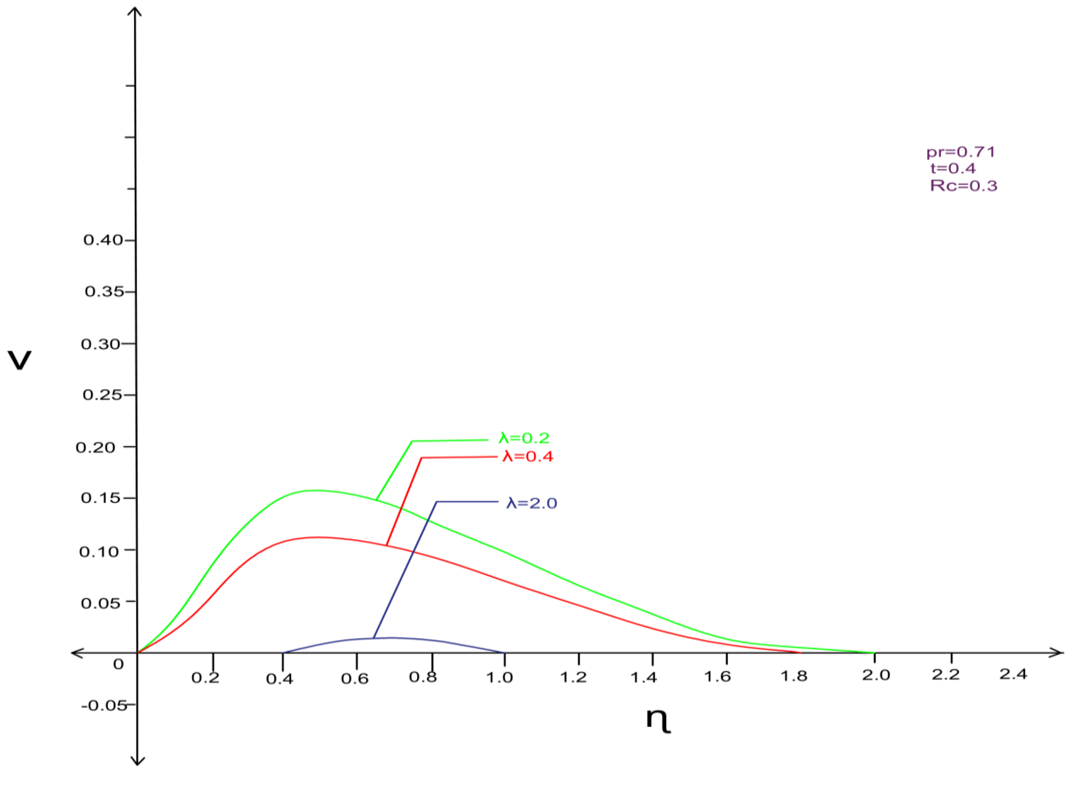



**Fig 12:- As Transverse velocity fall down permeability parameter λ rises**

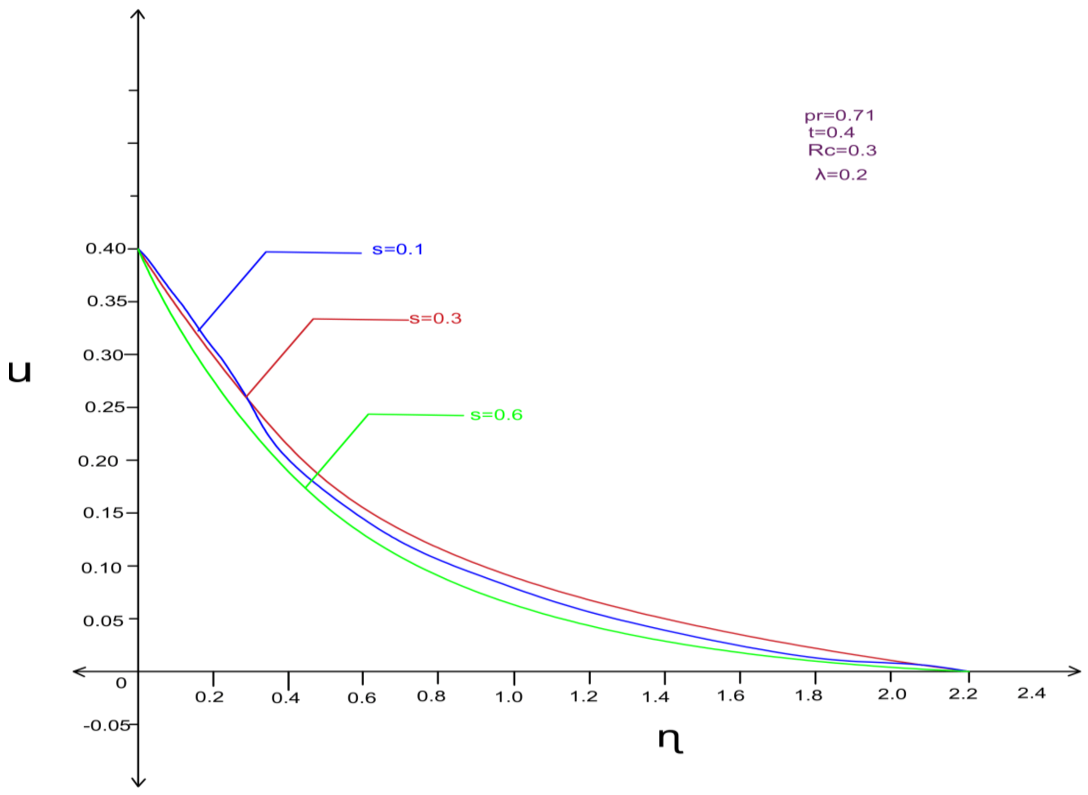



**Figure 13:- As S increases the flow become unstable.**

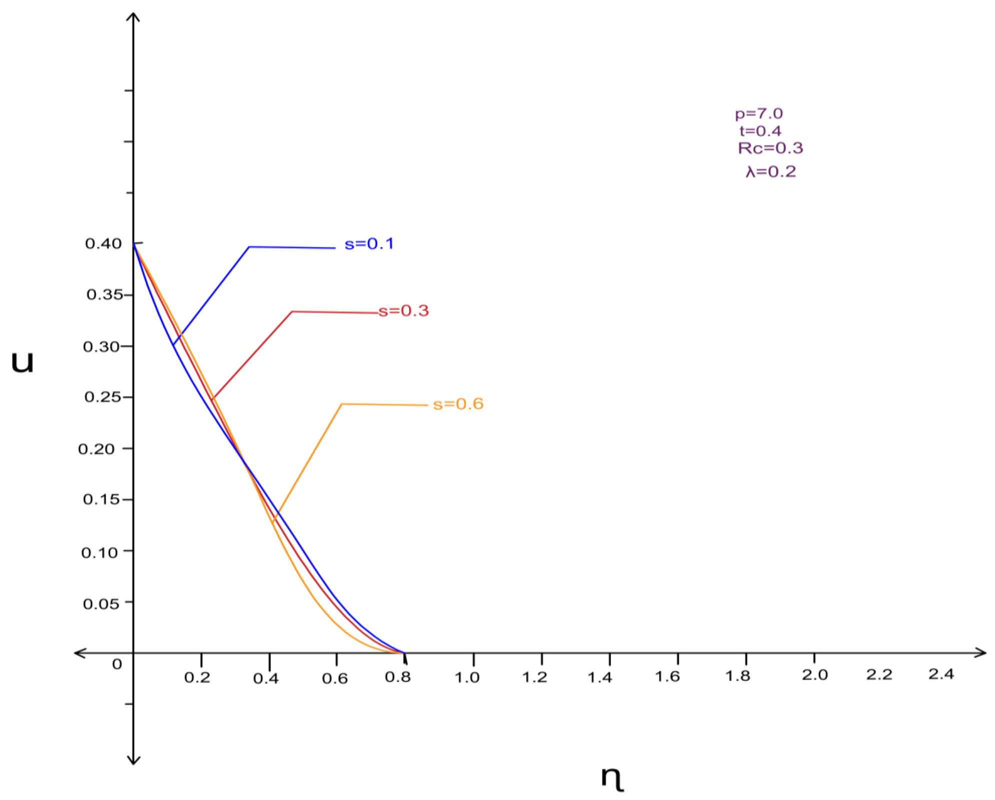



**Fig 14:- Heat source S increases flow destabilizes.**

The values of $\tau_x$ and $\tau_y$ that we calculated are shown in table (1) and table(2).

| **T** | **Pr** | **Rc** | $\lambda$ | **S** | $\tau_x$ | $\tau_y$ |
|---|---|---|---|---|---|---|
| 0.2 | 7 | 0.3 | 0.2 | 1.0 | 1.22574418 | -0.66187641 |
| | | 0.5 | | | 0.81433142 | -0.85911371 |
| | | 0.7 | | | 0.46970150 | -0.90330176 |
| 0.4 | 7 | 0.3 | | | 0.88262049 | -0.71792942 |
| | | 0.5 | | | 0.45122487 | -0.98870501 |
| | | 0.7 | | | 0.10260783 | -1.11129436 |
| 0.4 | 7 | 0.3 | 0.2 | | 0.88262049 | -0.71792942 |
| | | | 0.4 | | 0.85896631 | -0.63538021 |
| | | | 2.0 | | 0.26439082 | -0.34623902 |
| 0.4 | 7 | $10^2$ | 0.2 | | -8.15651106 | -2.37960730 |
| | | $10^1$ | | | -2.76254343 | -0.63336584 |
| | | $10^0$ | | | -0.24802856 | -1.18530425 |
| | | $10^{-1}$ | | | 1.25741373 | -0.22405360 |
| | | $10^{-2}$ | | | 1.32922533 | 0.01311695 |
| | | $10^{-3}$ | | | 1.33040091 | 0.01290997 |
| | | $10^{-4}$ | | | 1.33042529 | 0.00495170 |
| | | $10^{-5}$ | | | 1.33042593 | 0.00164498 |
| | | $10^{-6}$ | | | 1.33042595 | 0.00052029 |
| | | 0.3 | | 0.1 | 0.88262049 | -0.71792942 |
| | | | | 0.3 | 1.13411215 | -1.82291452 |
| | | | | 0.6 | 1.10446144 | -1.17144300 |
| | 100 | | | 1.0 | 0.56613362 | -0.73638280 |

**Table 3:**

| T | Pr | Rc | $\lambda$ | S | $\tau_x$ | $\tau_y$ |
|---|---|---|---|---|---|---|
| 0.2 | 0.71 | 0.3 | 0.2 | 1.0 | 8.62103372 | -10.95635123 |
| | | 0.5 | | | -4.59762423 | 6.55878119 |
| | | 0.7 | | | 10.42511386 | -15.39634820 |
| 0.4 | 0.71 | 0.3 | 0.2 | | 3.93386054 | 0.28012653 |
| | | | 0.4 | | 4.43147854 | -0.15699042 |
| | | | 2.0 | | 4.20006115 | -0.31264888 |
| 0.4 | 0.71 | 0.3 | 0.2 | | 3.93386054 | 0.28012653 |
| | | 0.5 | | | 1.38335848 | 7.66564311 |
| | | 0.7 | | | 3.22063280 | -13.55449075 |
| | | $10^2$ | | | 6.43250478 | -4.34682595 |
| | | $10^1$ | | | -2.28013059 | -0.85591805 |
| | | $10^0$ | | | 1.55188483 | -3.56100578 |
| | | $10^{-1}$ | | | 5.33684923 | -0.28083186 |
| | | $10^{-2}$ | | | 5.54390164 | -0.03263622 |
| | | $10^{-3}$ | | | 5.54604257 | -0.00328813 |
| | | $10^{-4}$ | | | 5.54606402 | -0.00034876 |
| | | $10^{-5}$ | | | 5.54606424 | -0.00005482 |
| | | $10^{-6}$ | | | 5.54606424 | -0.00002543 |
| | | | | 0.1 | 7.91581978 | -14.14168621 |
| | | | | 0.3 | 20.14180352 | -26.83381098 |
| | | | | 0.6 | -2.59760652 | 5.98039405 |
| | 0.1 | | | 1.0 | 3.93386054 | 0.28012653 |

## Conclusion:

The flow of air and water under many conditions are shown by our investigation. We found that for water, axial velocity increases and transverse velocity decreases as the rotation parameter Rc increases. At increasing densities, the permeability parameter λ exhibits oscillating behaviour, which reduces flow. The flow of air exhibit more unpredictable features. As Rc falls, the axial velocity becomes more unstable and as λ increases the flow oscillates. The heat source S increase, the flow becomes inconsistent. The axial velocity steadily decreases as the Prandtl number rises.

Skin friction analysis revealed different behaviours between water and air. As heat source S rises axial and transverse skin friction oscillates for air and water. Axial skin friction falls for water and unstable for air for permeability parameter $\lambda$ where transverse skin friction increases for water and fall for air. For Rotational parameter Rc, axial and transverse skin friction both fall whereas axial and transverse skin friction both oscillates.

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