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CHARACTERISTIC OF BLOOD FLOW THROUGH AN INCLINED ARTERY: EFFECT OF BODY ACCELERATION, MAGNETIC FIELD IN PRESENCE OF STENOSIS

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Abstract: In this paper effects of body acceleration using wall slip velocity on pulsatile flow of blood through an inclined stenosed artery under the influence of magnetic field is analyzed. Perturbation technique with finite Difference scheme is applied to find velocity, flow rate, wall shear-stress and viscosity. The variation of velocity, flow rate and viscosity with different parameters like time ,radial distance, axial distance, inclination angle, Hartmann-number, body acceleration parameter, stenosis geometry i.e. height of the stenosis, pressure gradient parameter, amplitude of oscillatory part of pressure gradient, slip velocity have been shown graphically . It is observed that velocity increases as inclination angle and slip velocity increases and velocity decreases with increasing value of magnetic field .Effect of pressure gradient parameter and body acceleration parameter depends on time. It is also observed that blood viscosity increases with increasing values of Hartmann number.

I. INTRODUCTION

Human body consists of mesh of different types of arteries some are horizontal and some are inclined. In inclined artery the force of gravity has important role. Due to this reason blood flow through an inclined artery is essential. Heart is a muscular pump and pressure difference in its systolic and diastolic conditions creates pressure pulse, this nature of heart generates pulsatile conditions in all arteries. Atherosclerosis-the leading cause of death. Under diseased conditions, abnormal and unnatural growth in to lumen of the artery restricts the flow of blood. Due to this coupling between growth of stenosis and the flow of blood , the detailed knowledge of the flow field in an inclined stenosed artery is beneficial in proper understanding and prevention of arterial diseases.Many researchers Prasad and Radhakrishnamacharya [2008], Sreenadh et. al. [2011], Chakraborty et.al.[2011] discussed the flow of blood through an inclinedartery in the presence of stenosis or multiple stenosis taking blood as different type of fluid like Herschel-Bulkley,casson etc. They observed the effects of various parameters shear stress, wall shear stress,inclination angle etc. on blood flow. Biswas and Paul [2013] studied the steady flow of blood through an inclined tapered constricted artery with an axial slip in the velocity at the tapered vessel wall and investigated the combined influence of tapering angle, slip at wall, inclined artery, Newtonian nature and non-symmetrical stenosis.

In past three years due to COVID-19 use of electromagnetic gadgets, like computer, mobile, laptop etc. which have some magnetic field effect becomes more common. This magnetic field affects the blood flow velocity and causes many health issues such as depression,headache, vomiting tendency, partial loss of vision etc. So study of effect of magnetic field on blood flow has its importance..Biswas and Laskar [2011]and Mathur and Jain [2011] studied the effect of uniform magnetic field on unsteady flow of blood through a stenosed artery with body acceleration .Tripathi [2012] studied the characteristic of flowing blood through flexible inclined arteries under the effect of inclined magnetic field assuming blood as couple stress fluid and the geometry of wall surface of inclined artery as peristaltic wave.

When we are doing activities like running on treadmill, travelling in bus and train, horse riding our body subjected to different coupling of amplitudes and frequencies of vibrations ,this effects on different parts of the body and the blood flow. It causes many health issues increases in pulse rate,hemorrhage in the face,neck,eye socket,lungs and brain.But the suitable range of amplitude and frequency for fix time can be use for fat reduction, strengthening muscles etc. Neeraja and K. Vidya [2012] studied pulsatile flow behavior of blood in an inclined artery under stenotic condition subject to both the pulsatile pressure gradient due to normal heart action and of periodic body acceleration and found that the body acceleration parameter, inclination and radius of stenosis are the strong parameters influencing the flow qualitatively and quantitatively. Sanyal et.al. [2007] studied the effect of magnetic field, gravitational parameter, inclination angle, body acceleration, time etc. on axial blood flow, flow rate and acceleration of blood graphically by developing mathematical model of pulsatile flow of blood through an inclined circular tube.Srivastava N.[2014] obtained the axial velocity shows the remarkable changes with the inclination of artery. Velocity increases with increase of inclination, time, body acceleration to after some limit it decreases is observed by Kakati et.al.[2018]. Prasad K. et.al.[2021] studied a model in which it is assumed that blood is mixed with nanoparticles and flowing through the inclined tapered artery with mild stenosis in influence of magnetic field. Pokhrel Puskar et.al.[2020] analyzed flow parameters in influence of stenosis . Kumar Ajay et. al.[2016] developed a model of blood flow in an inclined tapered artery under MHD effect.

In this work an attempt has been made to study the pulsatile flow of blood through an inclined stenosed artery under the influence of magnetic field and body acceleration assuming blood as Newtonian fluid. Perturbation technique and Finite Difference Method is used for calculating velocity. Effects of body acceleration, magnetic field, inclination angle and wall slip velocity etc. on flow parameters are discussed graphically and in tabular form.

II. FORMULATION OF THE PROBLEM

Following assumptions are made:

a) Blood flow as pulsatile, one dimensional, laminar, fully developed
b) Flowing blood as homogenous,Newtonian fluid.
c) Presence of mild stenosis in the artery.
d) Artery is inclined at the angle *al* to the horizontal direction.
e) Body acceleration and slip velocity on artery wall.
f) Uniform transverse magnetic field is acting along the radius of the tube.

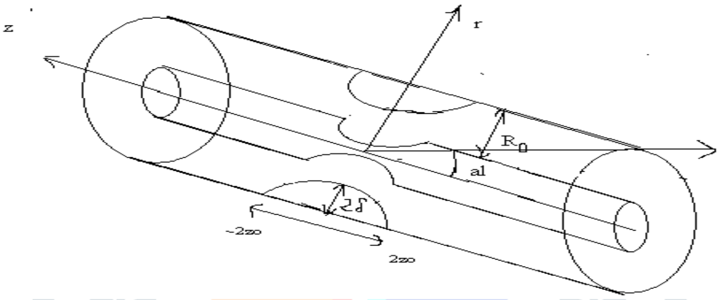

Figure 2.1: Geometry of the stenosis

The stenotic protuberance is assumed to be an axisymmetric surface generated by a cosine curve Neeraja and K. Vidya [2012].

$$R(z)=\begin{cases} R_0-\delta\left(1+\cos\left(\dfrac{\pi z}{2z_0}\right)\right) & -2z_0\le z\le 2z_0 \\ R_0 & otherwise \end{cases} \qquad (2.1)$$

where $4\,z_0$ is the length of the stenotic region, 2δ is the maximum protuberance of the stenotic form of the artery wall and R_0 is the radius of the tube in non-stenotic region.

III. GOVERNING EQUATIONS :

The pressure gradient and the time periodic body acceleration are given by {Biswas and Laskar [2011]}:

$$-\frac{\partial p}{\partial z}=A_0+A_1\cos\left(\omega_p t\right), \qquad t\ge 0 \qquad (3.1)$$

where A_0 is the steady component of the pressure gradient, A_1 is the amplitude of the fluctuating component of the pressure gradient and $\omega_p=2\pi f_p$, f_p is the pulse frequency in Hz.

$$F(t)=a_0\cos\left(\omega_b t+\phi\right), \qquad t\ge 0 \qquad (3.2)$$

where a_0 is the amplitude and $\omega_b=2\pi f_b$, f_b is the frequency in Hz and is assumed small so that wave effect can be neglected and ϕ is the phase difference.

The governing equation for blood flow can be modeled by Navier-Stoke's equation:

$$\rho\frac{\partial u}{\partial t}=-\frac{\partial p}{\partial z}-\frac{1}{r}\frac{\partial}{\partial r}(r\tau)+F(t)+\rho g\sin(al)-B_0^2\sigma u \tag{3.3}$$

where ρ is density of the fluid, B_0 is the the external magnetic field along the radial direction, σ is the conductivity of the fluid, τ is the shear stress and al is small angle of inclination.

The constitutive equation for Newtonian fluid is given as

$$\tau=-\mu\frac{\partial u}{\partial r} \tag{3.4}$$

The volumetric flow rate is given by

$$Q(z,t)=2\pi\int_0^{R(z)} ru(z,r,t)dr \tag{3.5}$$

The effective viscosity is defined as

$$\mu=\frac{\pi\left(\frac{-\partial p}{\partial z}\right)(R(z))^4}{Q(t)} \tag{3.6}$$

BOUNDARY CONDITIONS

τ is finite and $\frac{\partial u}{\partial r}$ =0 at r=0. (3.7)

$u = u_s$ at r=R (3.8)

IV. RESULTS AND DISCUSSIONS

To get the flow behavior of blood through a inclined mild stenosed artery under periodic body acceleration and magnetic field, the variations of u have been computed using perturbation technique and then Finite Difference Method and the results are given in graphical and tabular form.

Figure 1-6 shows the axial velocity distribution in the presence of a mild stenosis in an inclined artery . Figure 1 illustrates the velocity distribution at z=-3.0 for different values of the pressure gradient parameter *e*. This figure reveals that velocity increases as the *e* increases when t € [0, 1.6471], [4.9412, 7.7647], whereas the reverse trend is observed in rest of the time interval. It also demonstrates that velocity decreases in time interval [0, 1.6471], [3.0588, 4.4706] and [6.1176, 8.000] and reverse trend is follows in the rest of the time interval. Crest of the oscillation in which velocity decreases as *e* increases is smaller than another. Highest velocity is occurred at t=0. Series of figure 2 shows variation of velocity variation w.r.t. radial distance r for different values of Hartmaan No. H, *e* and t. Figure 2 (A) reveals that velocity monotonically decreases as r increases at time t=1.1765 and velocity increases as *e* increases and decreases significantly as H increases .But at t=4.4706 velocity monotonically increases as r increases, effects of H is similar as t=1.1765 at *e*=0.5 but H effects reversely at *e*=0.6,0.7. It is interesting to note that if we take $e \le 0.4$ taking all parameter same velocity never negative it is shown in table 4.1.

Table.4.1

Variation of velocity w.r.t. r taking *e*=0.4 and H=2.5 at r=0.1147		
Sr.No.	**Time**	**Velocity**
1.	0.0	1.0245
2.	0.9412	0.3429
3.	2.1176	0.2415
4.	3.2941	0.6487
5.	4.4706	0.0038
6.	5.6471	0.7772
7.	6.8235	0.7129

Figure 2 (B) and 2 (C) illustrates velocity distribution w.r.t. r at different time t,H and *e*, which are in conformity with figure 1.Variation of velocity for different slip velocity u_s is plotted in figure 3.It represents that velocity increases with increasing u_s and decreases monotonically w.r.t. radial distance r. It is noted in computation that velocity monotonically increases with radial distance r if we take large value of H or u_s .Which is shown in table 4.2 and table 4.3.

Table 4.2

Variation of velocity w.r.t. r taking slip velocity =0.05 and H=8.5 at t= 0.9412		
Sr.No.	**radial distance**	**Velocity**
1.	0	0.0460
2.	0.3530	0.0461
3.	0.5492	0.0462
4.	0.5884	0.0463
5.	0.6668	0.0465
6.	0.7061	0.0466
7.	0.7453	0.0469
8.	0.7845	0.0472
9.	0.8237	0.0476
10.	0.8629	0.0481
11.	0.9022	0.0489
12.	0.9414	0.0500

Table 4.3

Variation of velocity w.r.t. r taking slip velocity =0.55 and H=2.5 at t= 0.9412		
Sr.No.	**radial distance**	**Velocity**
1.	0	0.5410
2.	0.3530	0.5417
3.	0.5492	0.5431
4.	0.5884	0.5434
5.	0.6668	0.5444
6.	0.7061	0.5449
7.	0.7453	0.5455
8.	0.7845	0.5462
9.	0.8237	0.5470
10.	0.8629	0.5479
11.	0.9022	0.5489
12.	0.9414	0.5500

It is observed that if we take u_s >0.05 we never gets negative velocity for the same values of the remaining parameters at time t=4.4706 it is shown in table 4.4.

Table 4.4

Variation of velocity w.r.t. r taking slip velocity =0.1, *e*=0.5 and H=2.5 at t= 4.4706		
Sr.No.	**radial distance**	**Velocity**
1.	0	0.0098
2.	0.3530	0.0195
3.	0.5492	0.0346
4.	0.5884	0.0387
5.	0.6668	0.0483
6.	0.7061	0.0483
7.	0.7453	0.0538
8.	0.7845	0.0599

9.	0.8237	0.0665
10.	0.8629	0.0738
11.	0.9022	0.0818
12.	0.9414	0.0905

Figure 4 demonstrates the velocity distribution for different values of stenosis height δ w.r.t. axial distance z..It reveals that as δ increases velocity decereases significantlyand H brings quantitative as well as qualitative changes in velocity profiles.The effects of the inclination angle *al* on velocity distribution at *e*=0.5 is shown in figure 5(A),5(B) and 5(C).Figure 5(A) represents the velocity distribution with the radial distance for different values of *al* at time t=1.1765.Figure 5(B) shows variation of velocity at time t=4.4706 it shows that velocity monotonically increases w.r.t. radial distance r. If we take *al* ≥0.4 at *e*=0.5, we will never obtain negative velocity at any time for H≤ 2.5, which is shown in table 4.5.

Table 4.5

Variation of velocity w.r.t. r taking inclination angle=0.4, *e*=0.5 and H=2.5 at t= 4.4706		
Sr.No.	**radial distance**	**Velocity**
1.	0	0.0030
2.	0.2746	0.0060
3.	0.3138	0.0070
4.	0.5884	0.0181
5.	0.6276	0.0205
6.	0.9022	0.0451
7.	0.9414	0.0500

Figure5(C) reveals the effects of *al* for velocity distribution at time t= 2.1176 and it shows same effects as figure 5(A).Figure 6 illustrates the variation of velocity w.r.t. time for different values of body acceleration parameter *A*. This figure shows that for any value of *A* velocity oscillates with time and it also represents that velocity increases with increasing value of *A* when t Є [0, 0.4706], [2.3529, 3.7647], [5.4118,6.8235],whereas the reverse trend is observed in rest of the time interval. It also demonstrates that number of oscillation increases in the presence of body acceleration in the same time period. We observed that for *A* <1.0 we never get negative velocity for the same values of the remaining parameters at *e*=0.5 it is shown in table 4.6.

Table 4.6

Variation of velocity w.r.t. t taking *A*=0.6, *e*=0.5 and H=0.5 at r=0.1147		
Sr.No.	**Time**	**Velocity**
1.	0.0	1.8241
2.	0.9412	0.9167
3.	2.1176	0.5461
4.	3.2941	0.9378
5.	4.4706	0.3206

6.	5.6471	1.4780
7.	6.8235	1.4212
8.	8.0000	0.4005

Figure 7-11 shows the variations of flow rate with respect to different parameters the Hartmaan No H, pressure gradient parameter *e*, slip velocity u_s, stenosis height δ, inclination angle *al* and body acceleration parameter *A*. Figure 7(A) illustrates variation of flow rate w.r.t pressure gradient parameter *e* for different values of Hartmann No. H at t=0.9412 and t=2.1176.It reveals that at t=0.9412 flow rate increases as value of *e* increases and at t=2.1176 flow rate decreases as *e* increases. Flow rate decreases at both times as H increases. It is interesting to note that at t=0.9412 effect of magnetic field increases as *e* increases and at t=2.1176 effect of magnetic field decreases as *e* increases. Figure 7(B) represents variation of flow rate w.r.t. *e* at t=4.4706.It shows that flow rate decreases as *e* increases and effect of H reverses after *e* =0.6. Figure 8(A) illustrates variation of flow rate w.r.t. slip velocity u_s at time t=0.9412 and t=2.1176 .We observed that the influence of magnetic field at time t=0.9412 is greater than at time t=2.1176 and effect of magnetic field increases as u_s increases. Figure 8(B) demonstrates variation of flow rate w.r.t. *e* for different values of u_s it shows that flow rate increase with slip velocity but effect of magnetic field reverses below 0.038.The distribution of flow rate for different values of stenosis height δ are presented graphically through series of figure 9.Figure 9(A) shows that flow rate decreases monotonically as δ and value of H increases. It reveals that effect of magnetic field decreases with δ.It is interesting to note that flow rate decreases rapidly from δ 0-0.2 .Figure 9(B) shows flow rate decreases with δ at time t=4.4706.We can observe at this time flow rate remains almost unchanged from δ 0-0.1 and then decreases rapidly this effect is reverse of figure 9(A).Variation of flow rate w.r.t. axial distance z for different values of δ is plotted in figure 9(C) .It shows that effect of δ is highest at the throat. Figure 9(D) depicts that flow rate decrease rapidly after H=0.5 and effect of δ decreases with increasing value of H. Figure 10(A), (B) and (C) demonstrates distribution of flow rate w.r.t. inclination angle *al* for different time t. Figure 10(A) and (B) depicts that the inclination of artery does not effect so much at the vicinity of the stenosis,but the flow rate decreases significantly w.r.t. increasing value of H. Figure 10 (C) reveals the variation of flow rate w.r.t. *al* and it shows that flow rate increase rapidly with *al* and H effects qualitatively for greater values of *al*. Variation of flow rate with body acceleration parameter *A* at different time t is plotted in figure 11.

The results for the effective viscosity computed on the basis of the present study are shown in figures 12-15 for the different values of the Hartmaan No H, pressure gradient parameter *e*, slip velocity u_s inclination angle *al* and body acceleration parameter *A*. Figure 12 shows variation of effective viscosity w.r.t. pressure gradient *e*. It indicates that at time t =0.9412 when velocity increases with *e*, effective viscosity decreases with increasing *e* and at time t=2.1176 reverse trend is follows by effective viscosity and it increase with increasing values of H at both time. It also depicts that effect of H increases significantly for large value of H.The variation of effective viscosity w.r.t. u_s is plotted in figure 13.It shows that effective viscosity decreases with u_s. Figure 14 represents that *al* almost does not effects at lower values of H on effective viscosity, but it can be observed that effective viscosity decreases with inclination of artery. Figure 15 gives variation of effective viscosity w.r.t *A* at different time.

Figure 16 shows the comparison of our results with those of computer generated results Biswas and Laskar [2011] for validation of our mathematical model. For this purpose we studied the both the problems at same platform assuming inclination angle zero in present study and taking remaining parameters same.

V. CONCLUSION

In present paper pulsatile blood flow through inclined stenosed artery under the influence of body acceration and in the presence of magnetic field with slip velocity on wall is investigated. In this study normally we take pressure gradient parameter *e*=0.5, inclination angle *al*=0.2,body acceleration parameter *A*=1.0 and slip velocity u_s=0.05. Here we notice that parameter is significant,as at time t=4.4706 velocity becomes negative it means there is reverse flow in artery. But as shown in tables 4.1,4.4,4.5 and 4.6 we can stop this reverse flow if we decrease value of *e* or *A* and increase the value of *al* or u_s. So we conclude that these parameters effects significantly on the blood flow through artery and by taking suitable range of these parameters we can control the blood flow conditions. From figure 10 we can conclude that inclination of the artery does not effect so much on the flow rate in the presence of the stenosis.

As magnetic field applied on body, the Laurentz force opposes the flow figures 1-6 shows that velocity decreases as magnetic field increases. By this study we can determine those regions where the velocity is low and chances of formation of stenosis is high as low velocity regions are occupied to the development of further deposition,

Figure 12-14 shows viscosity increases with increasing values of H in each situation for fix value of t .This fact is harmful for heart .Because thick blood can damage blood vessels and increases the heart attacks. Selection of suitable magnetic field strength and pulse duration able to controls the blood viscosity.

It is hoped that this paper will beneficial for taking suitable range of these parameters to development of better diagnostic tools ,better design of proctective pads and machines.

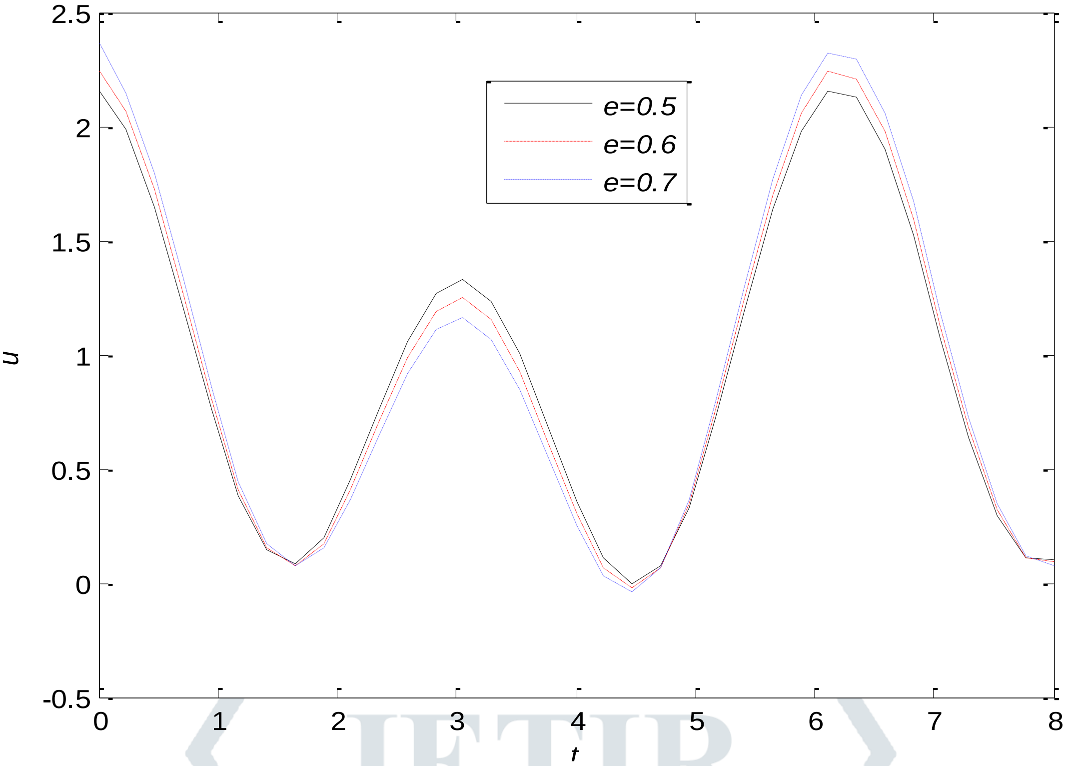

Figure 1: variation of velocity w.r.t. time t for different value of coefficient of oscillatory part of pressure gradient

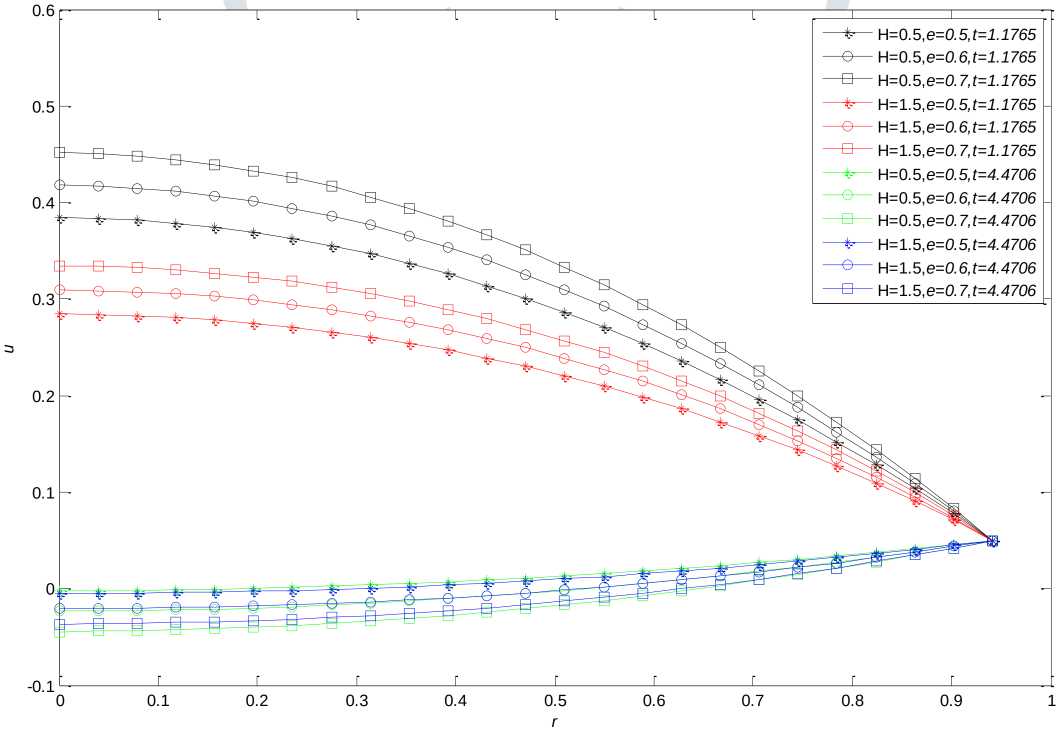

Figure 2(A): variation of velocity w.r.t. radial distance r for different values of H,t,*e*

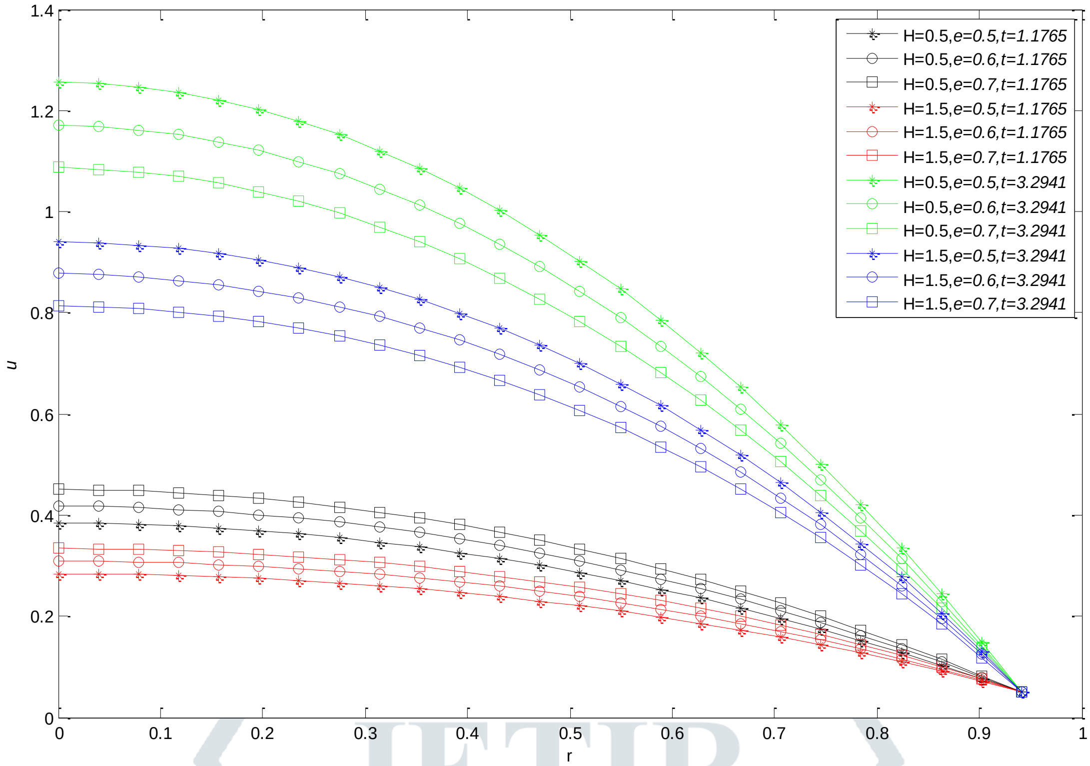

Figure2(B): variation of velocity w.r.t. radial distance r for different values of H,t,*e*

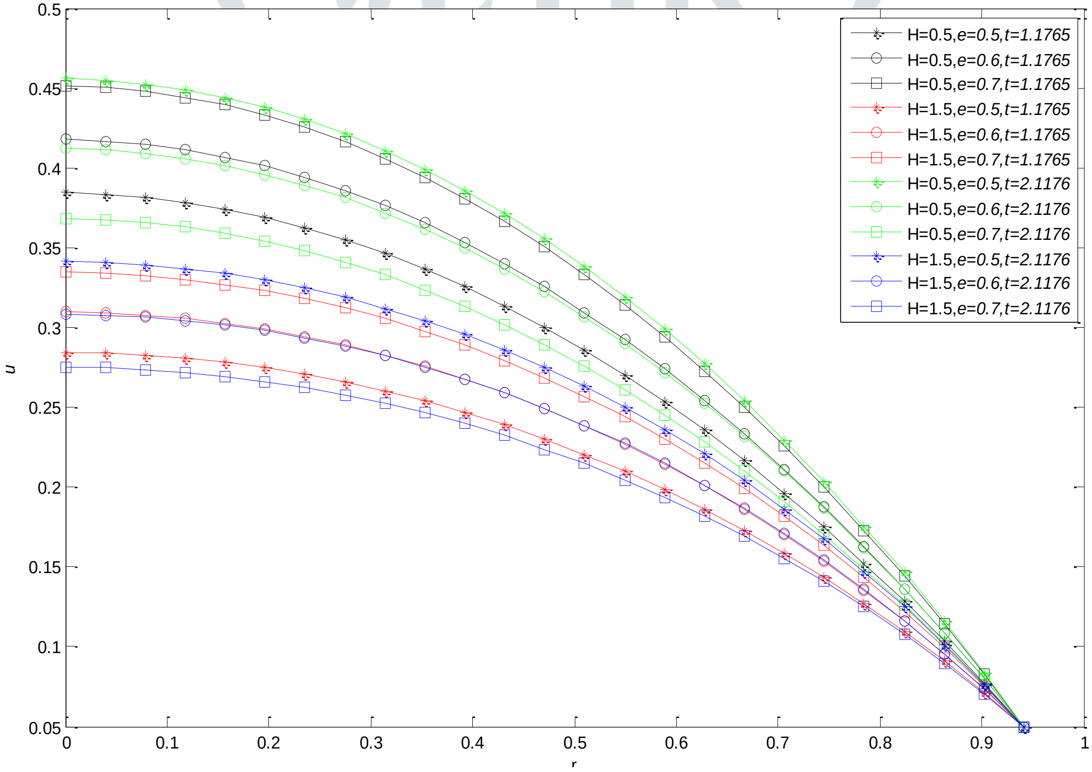

Figure2(C): variation of velocity w.r.t.radial distance r for different values of H,t,*e*

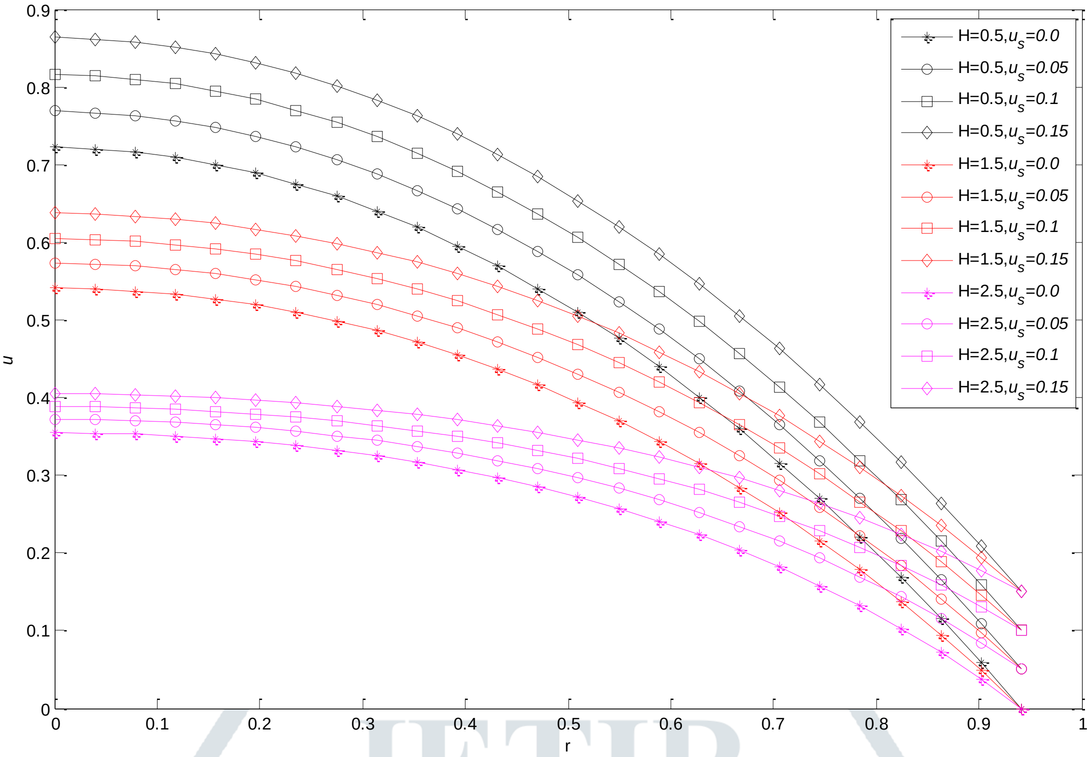

Figure3: variation of velocity w.r.t. radial distance r for different values of u_s and H

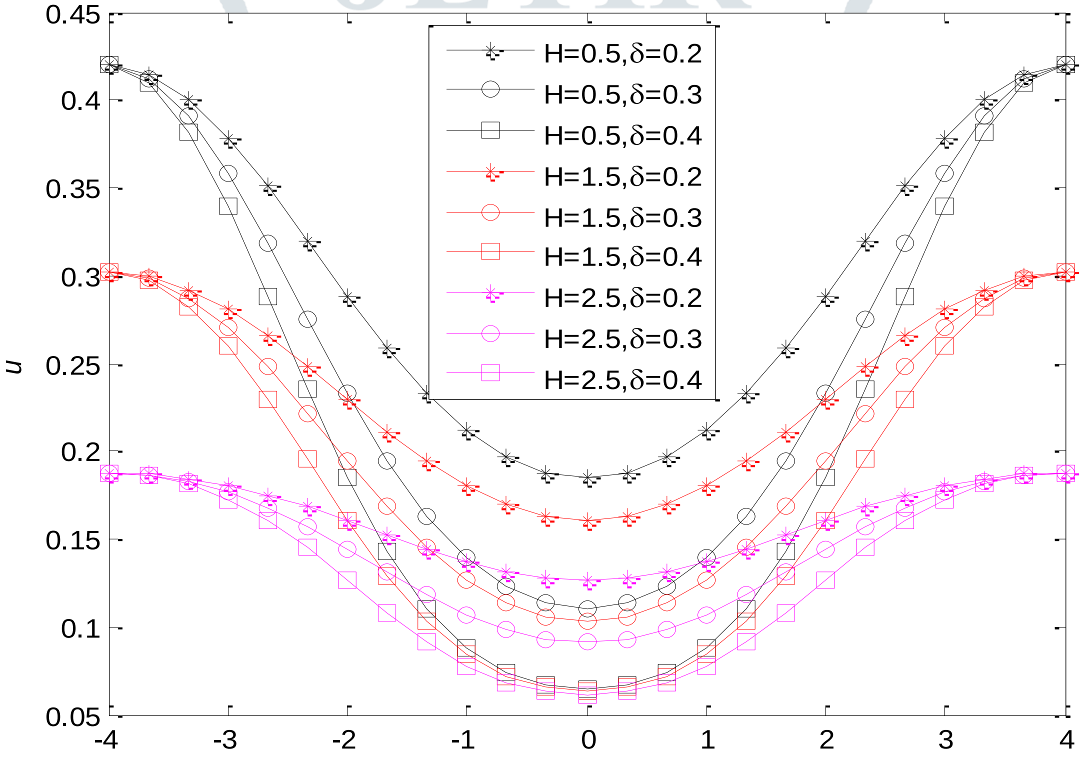

Figure4: variation of velocity w.r.t. axial distance z for different values of stenosis height δ

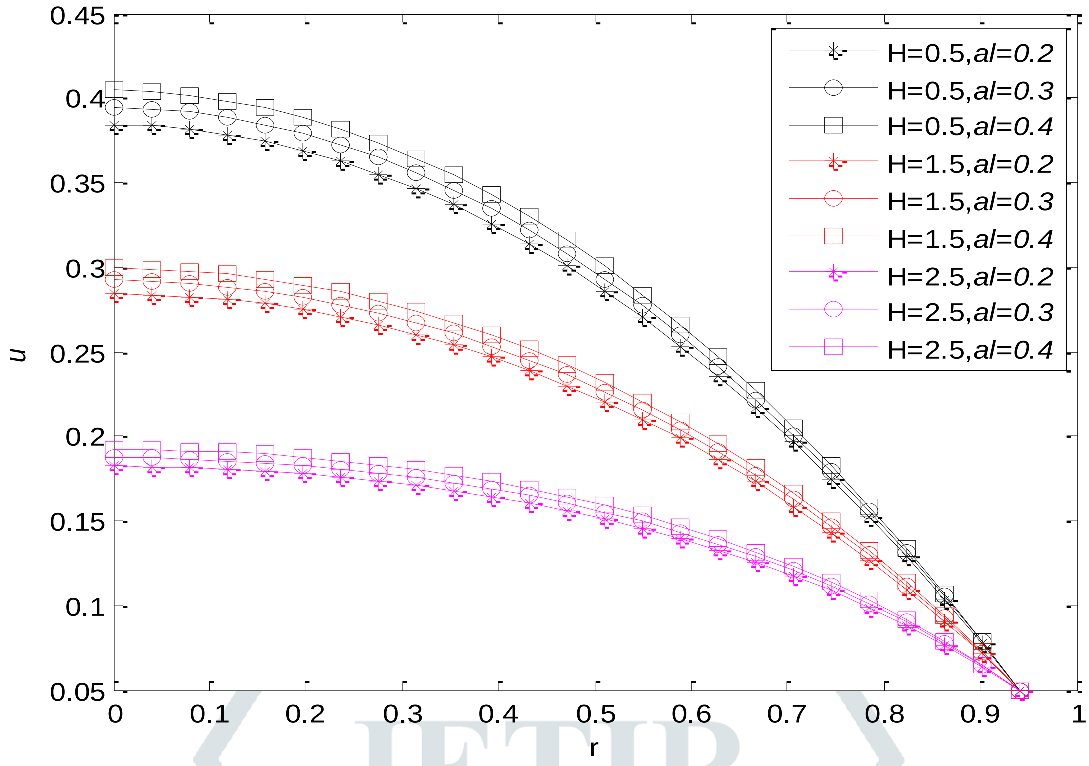

Figure5(A): variation of velocity w.r.t. radial distance r for different values of inclination angle *al*

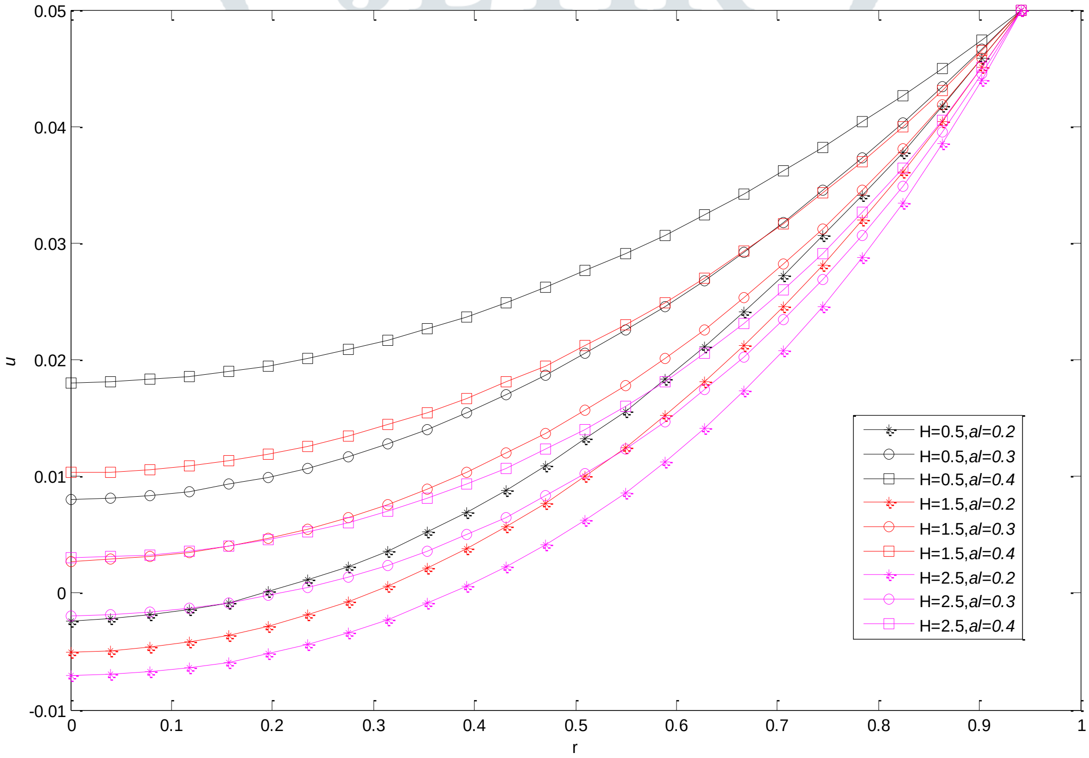

Figure5(B): variation of velocity w.r.t. radial distance r for different values of inclination angle *al*

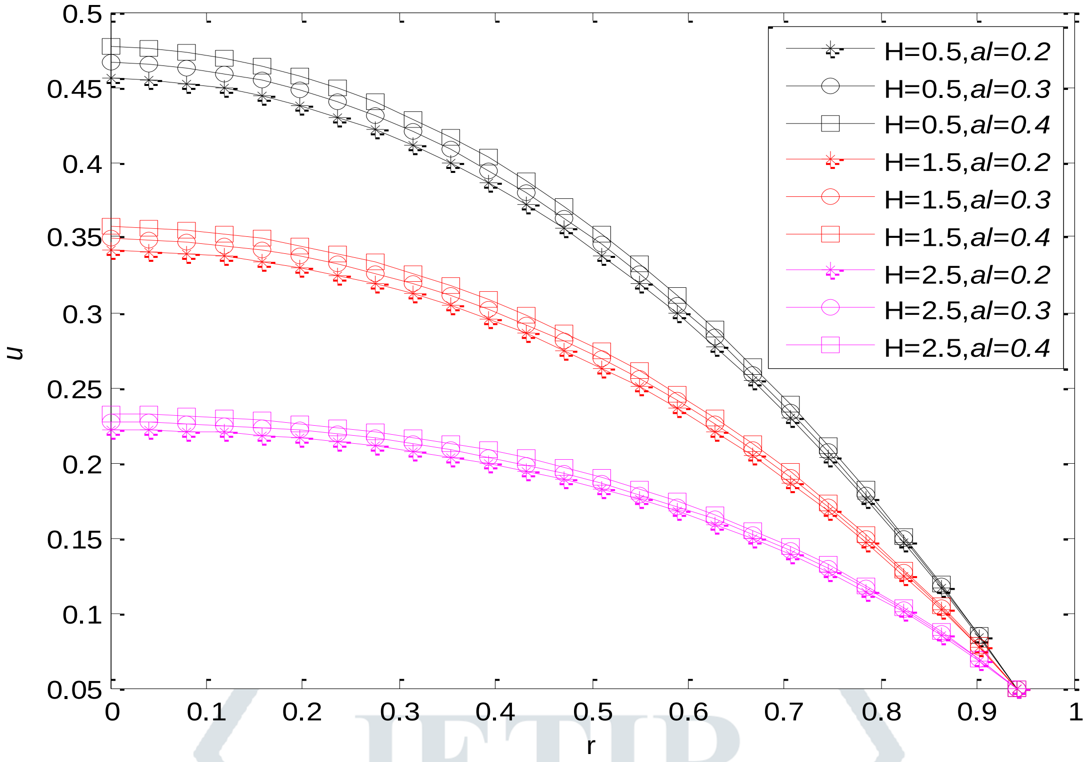

Figure5(C): variation of velocity w.r.t.radial distance r for different values of inclination angle *al*

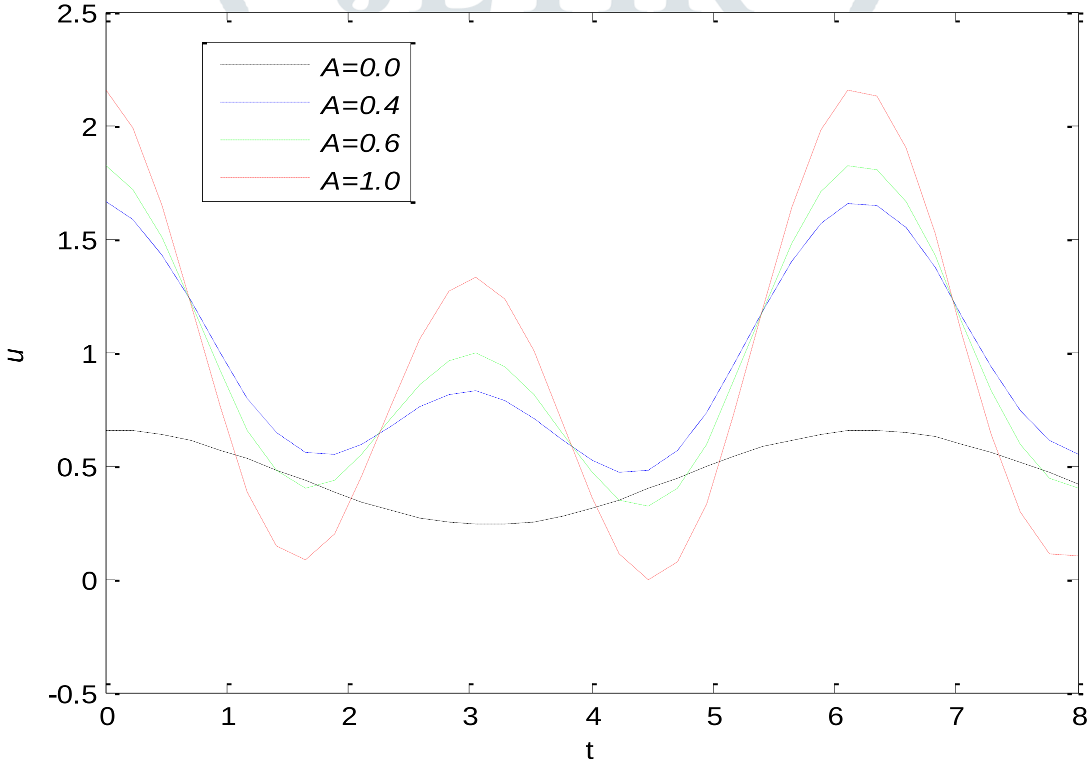

Figure6:variation of velocity w.r.t. time t for different values of body acceleration parmeter *A*

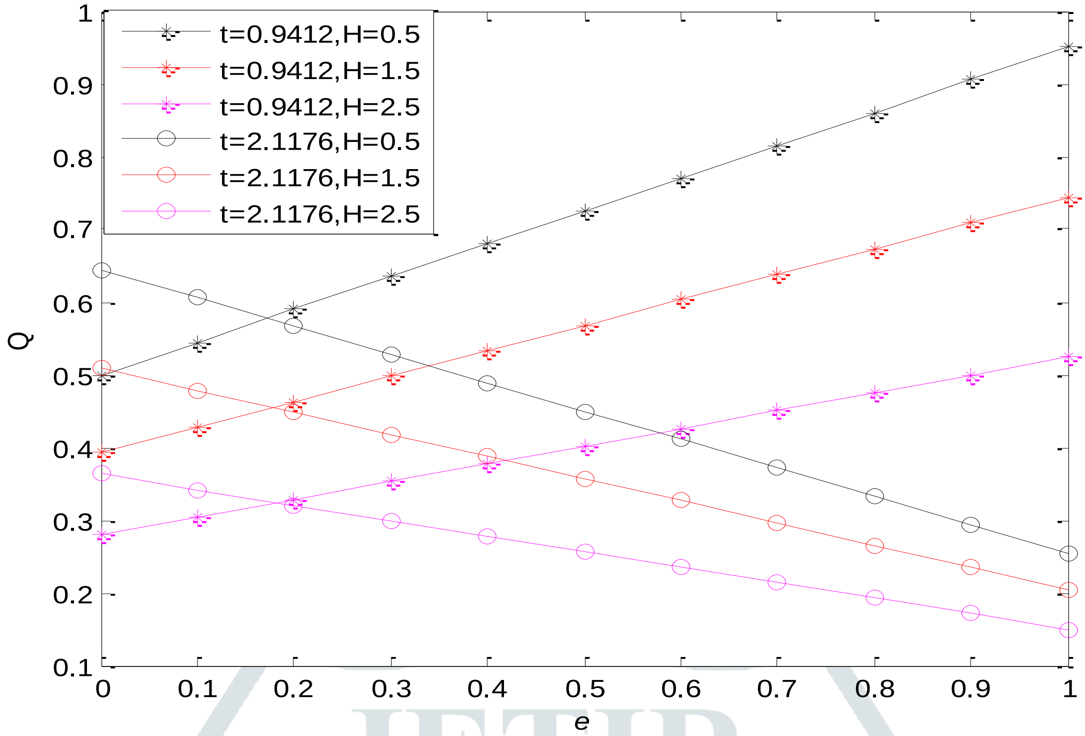

Figure7(A):variation of flow rate w.r.t. pressure gradient parameter e for different values of H and t

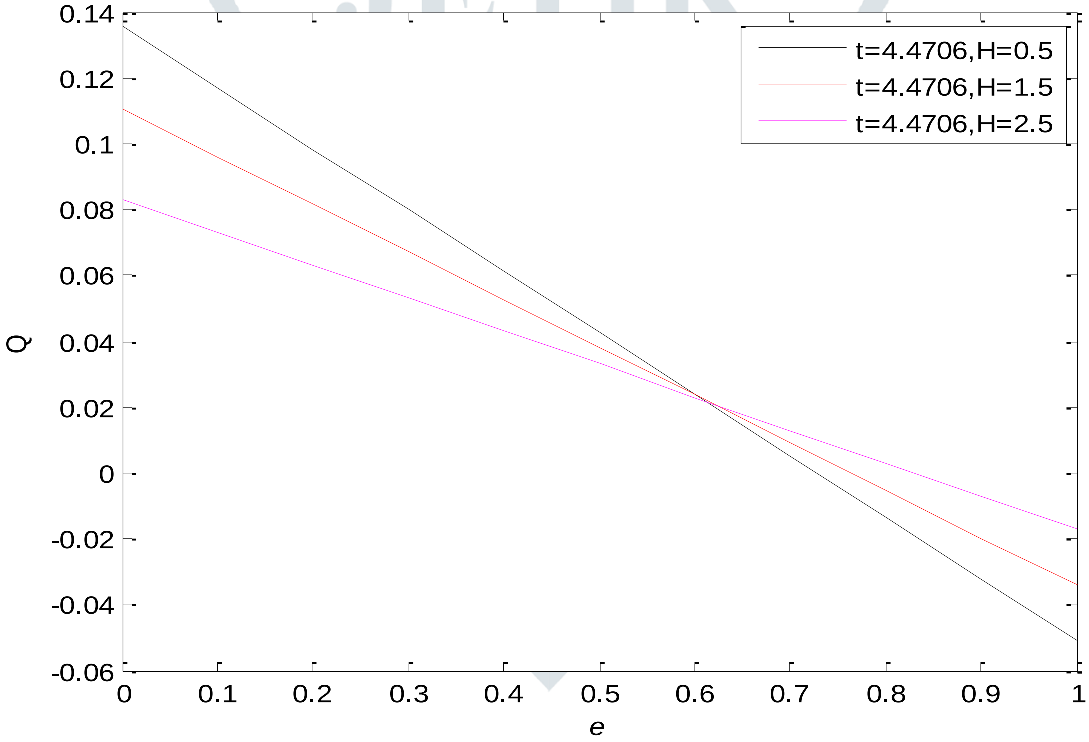

Figure7(B):variation of flow rate w.r.t. pressure gradient parameter e for different values of H and t

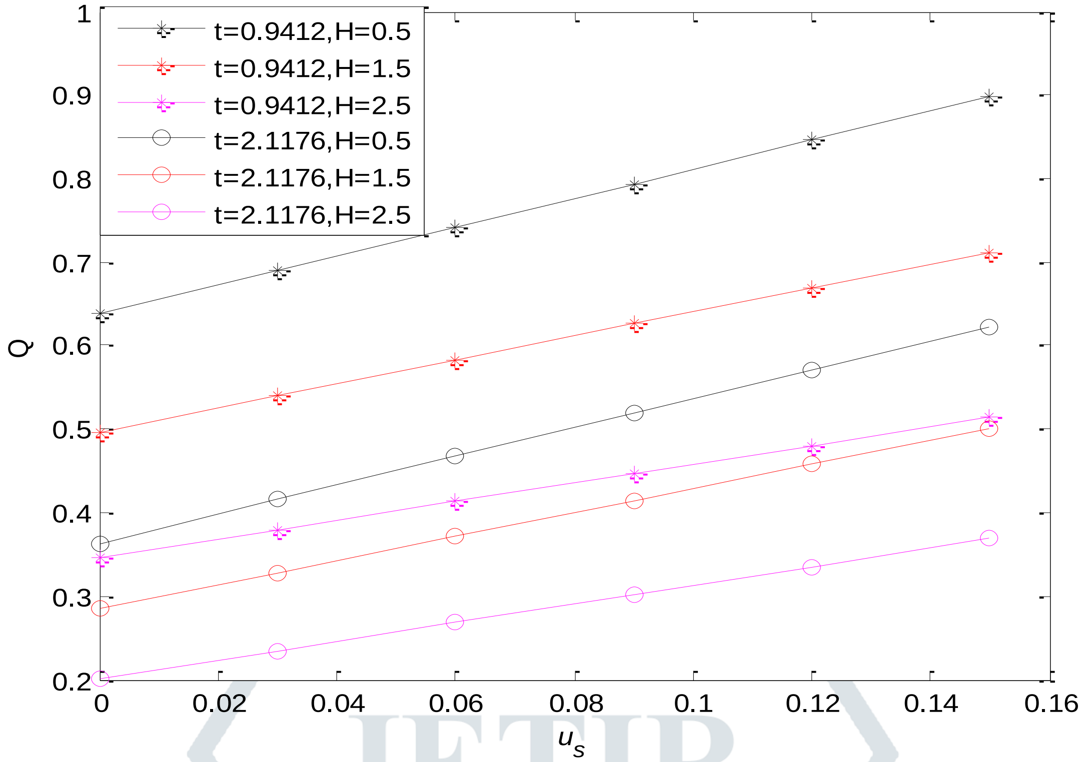

Figure8(A):variation of flow rate w.r.t. slip velocity u_s for different values of H and t

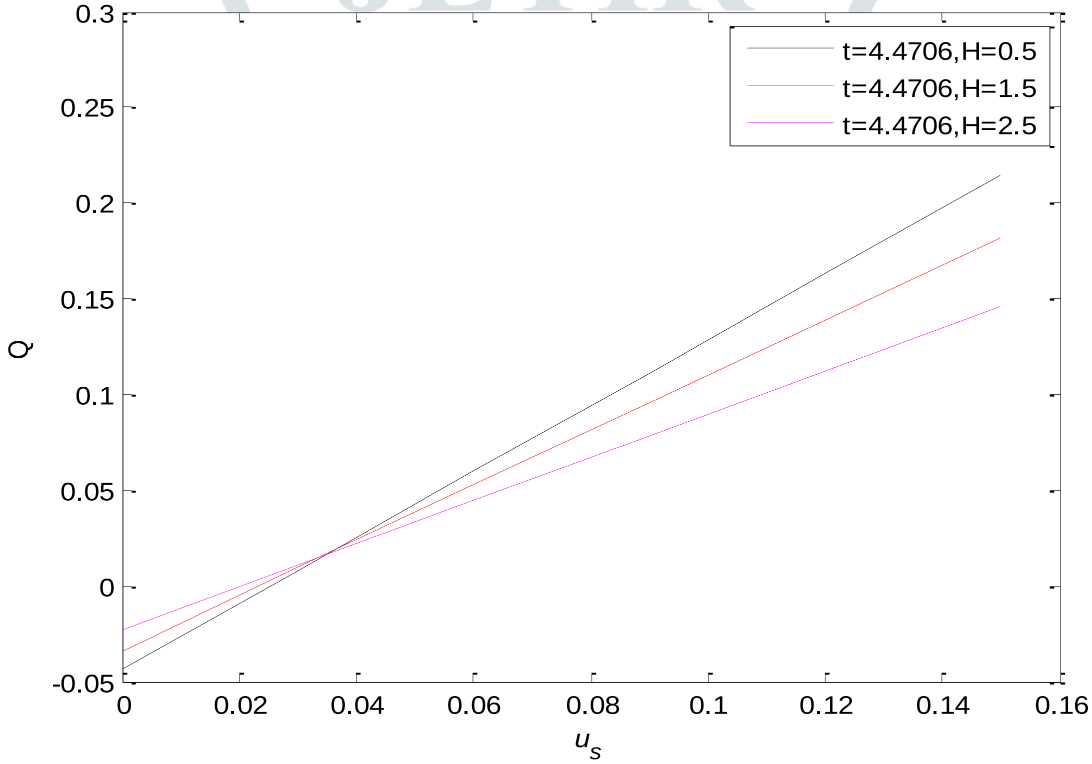

Figure8(B): variation of flow rate w.r.t. slip velocity u_s for different values of H and t

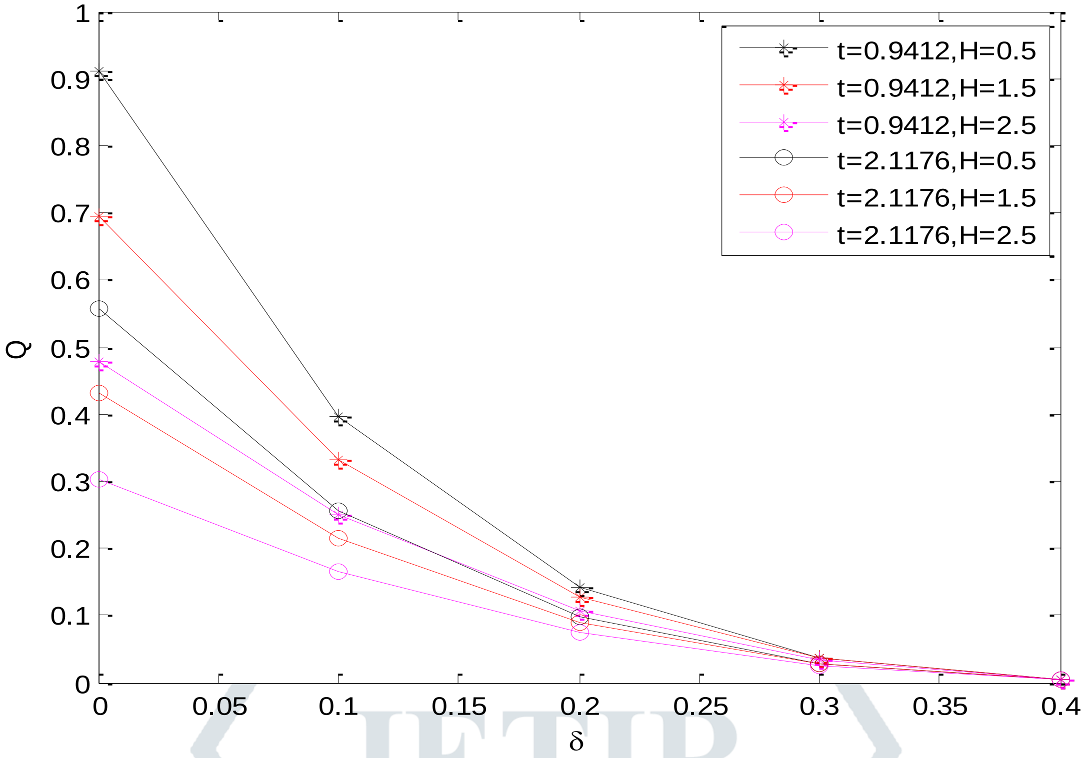

Figure 9(A): variation of flow rate w.r.t. stenosis height δ with different t

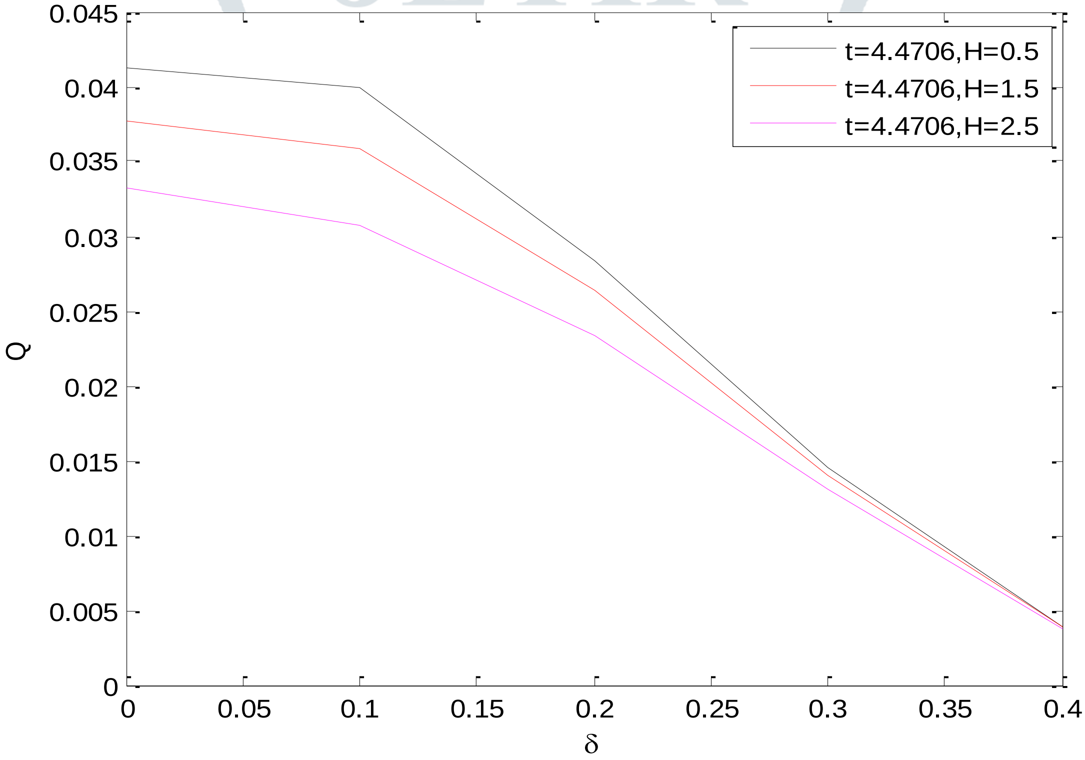

Figure 9(B): variation of flow rate w.r.t. stenosis height δ with different t

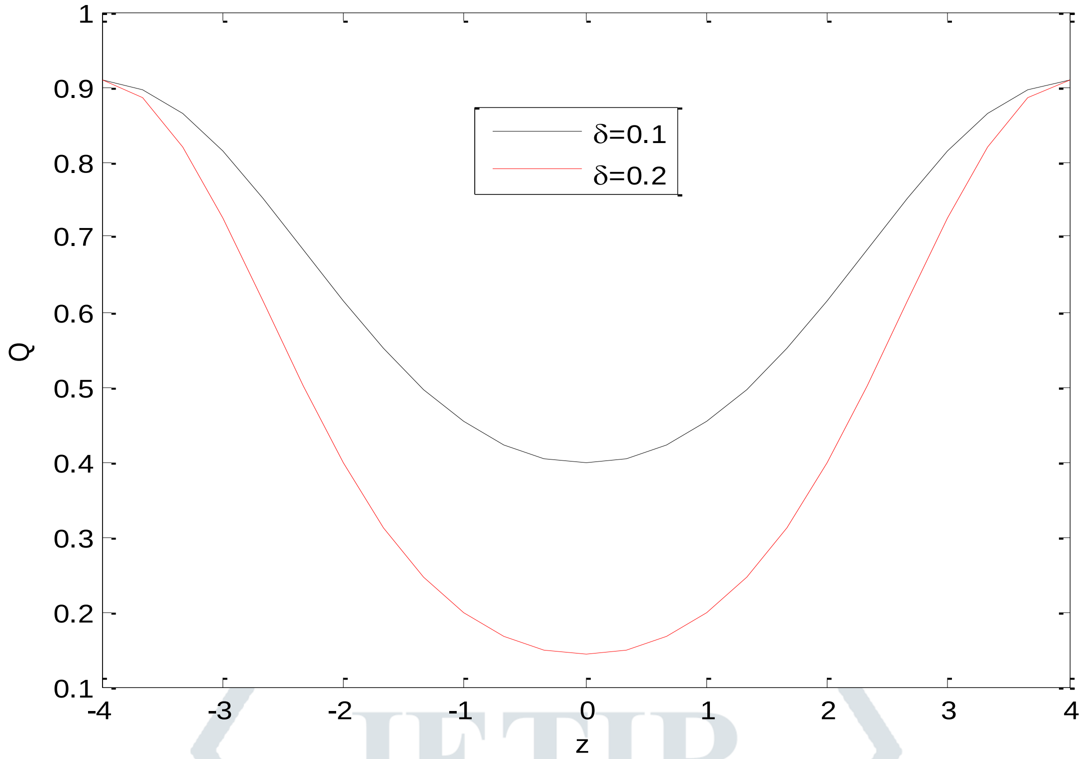

Figure9(C): variation of flow rate w.r.t. axial distance z for different value of stenosis height δ

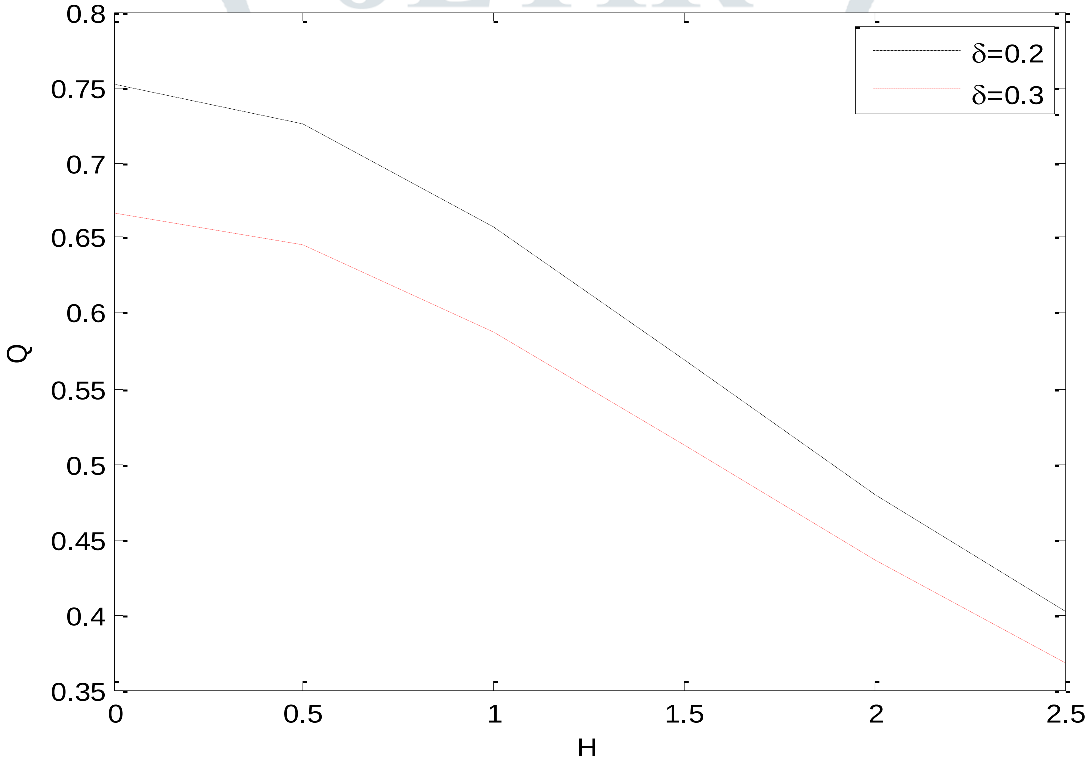

Figure 9(D): variation of flow rate w.r.t. Hartmann Number H for different value of stenosis height δ

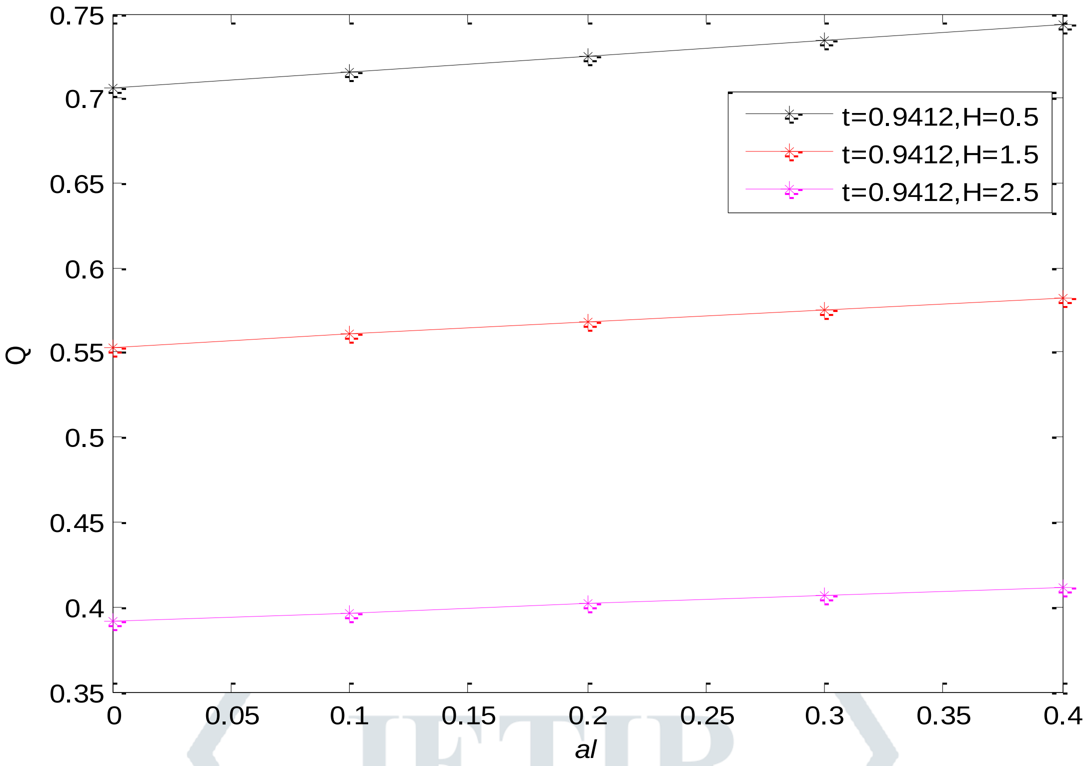

Figure10(A): variation of flow rate w.r.t. inclination angle *al* for different values of H and t

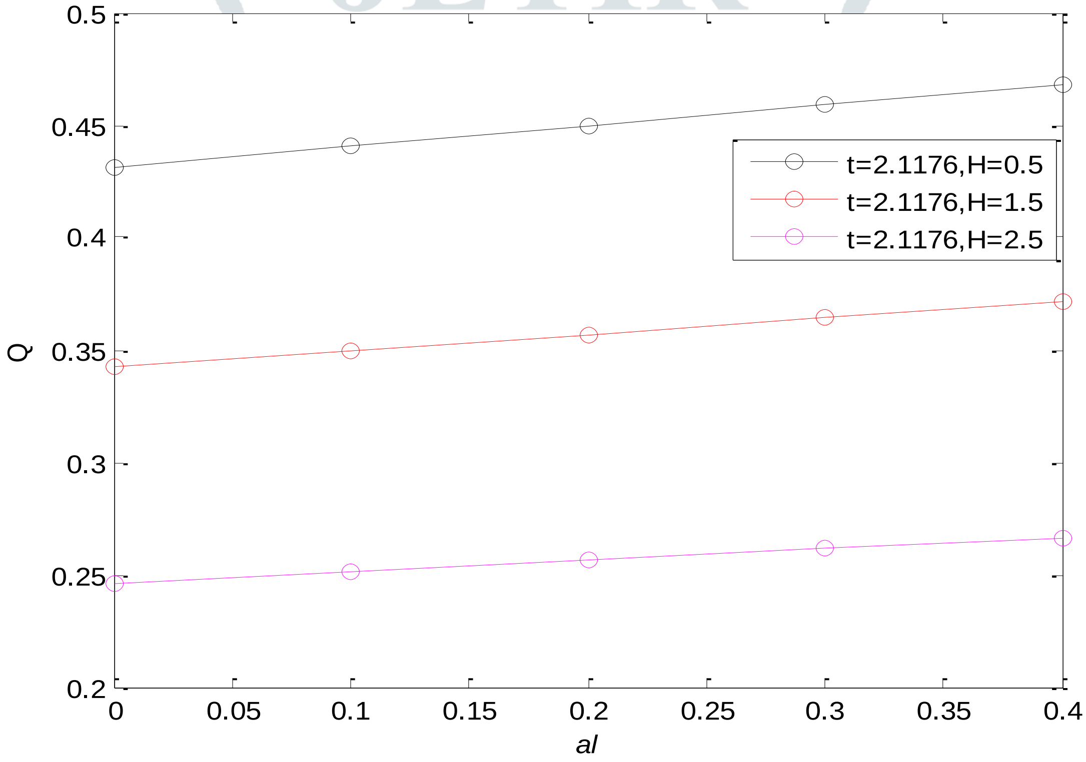

Figure10(B): variation of flow rate w.r.t. inclination angle *al* for different values of H and t

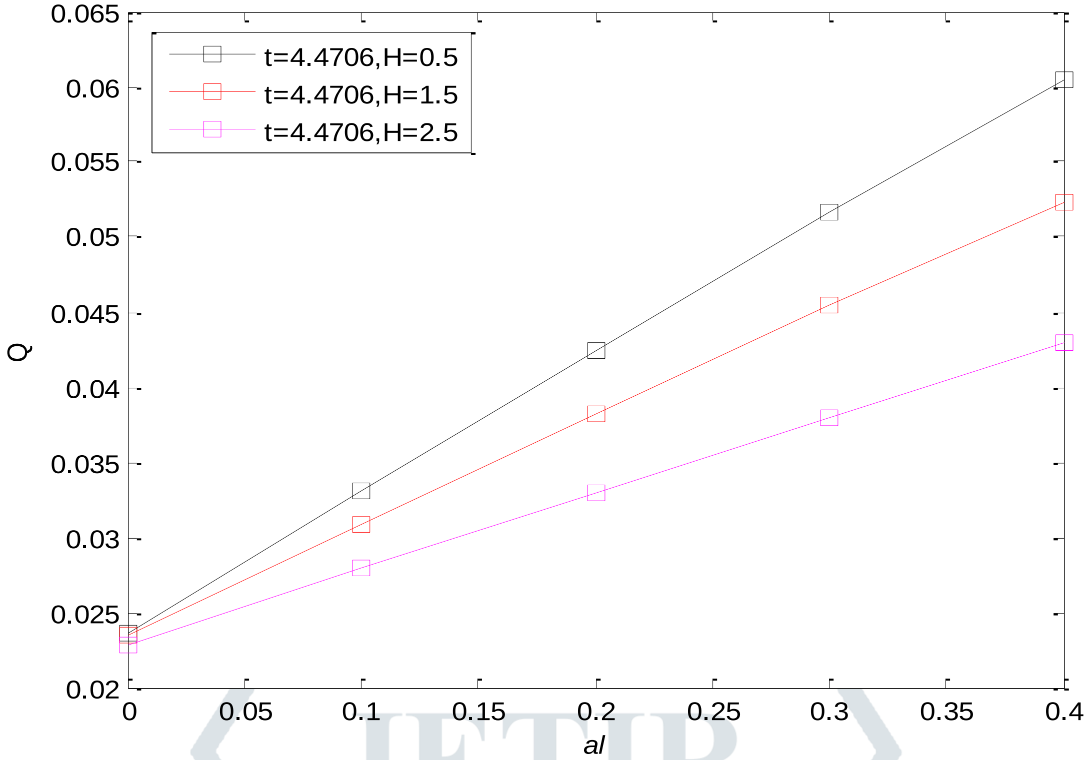

Figure10(C): variation of flow rate w.r.t. inclination angle *al* for different values of H and t

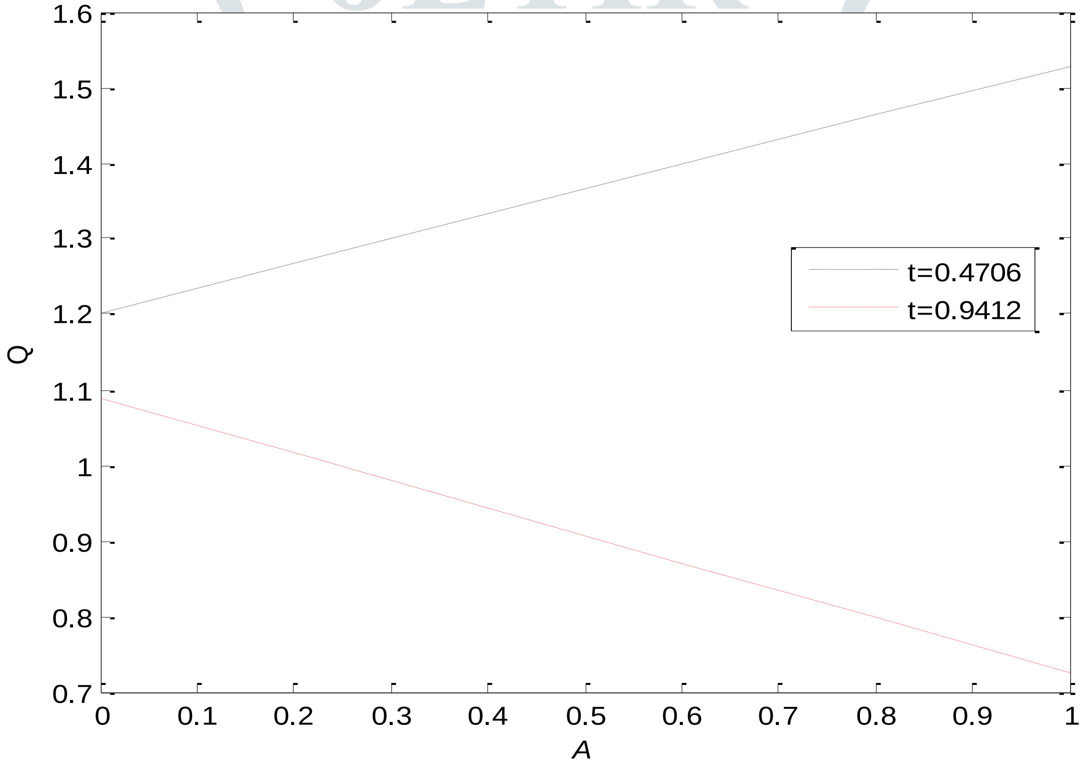

Figure11: variation of flow rate w.r.t. body acceleration parameter *A* for different values of t

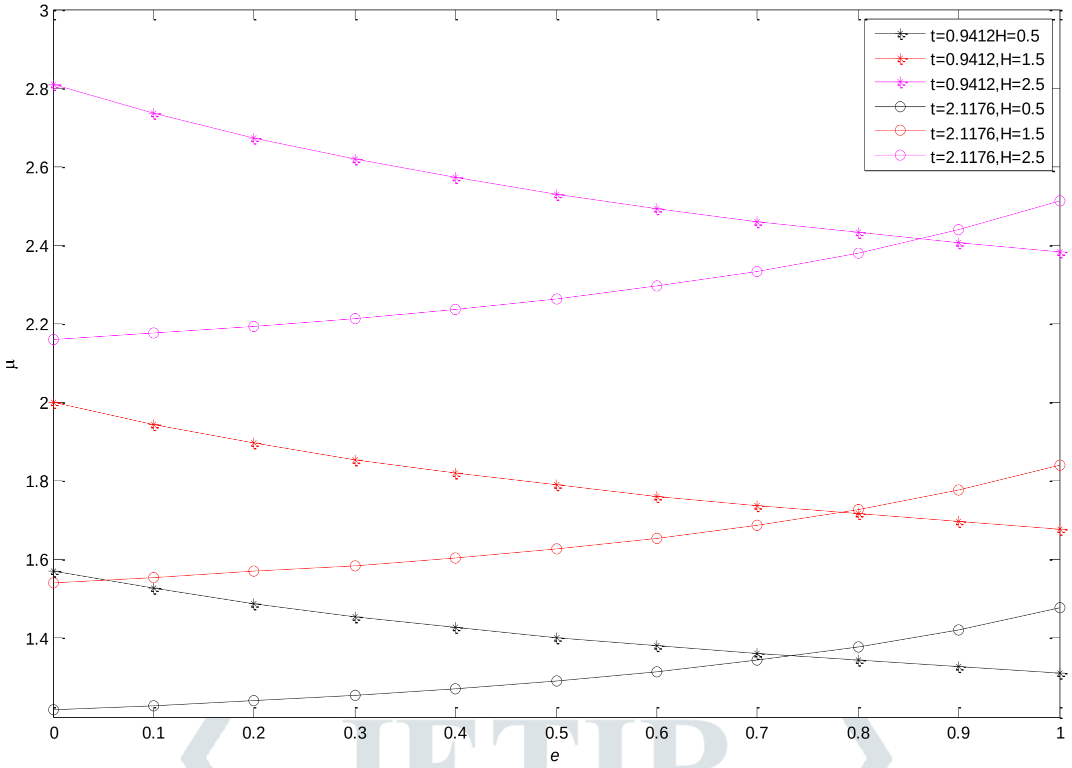

Figure12: variation of effective viscosity w.r.t pressure gradient parameter *e* for different values of H

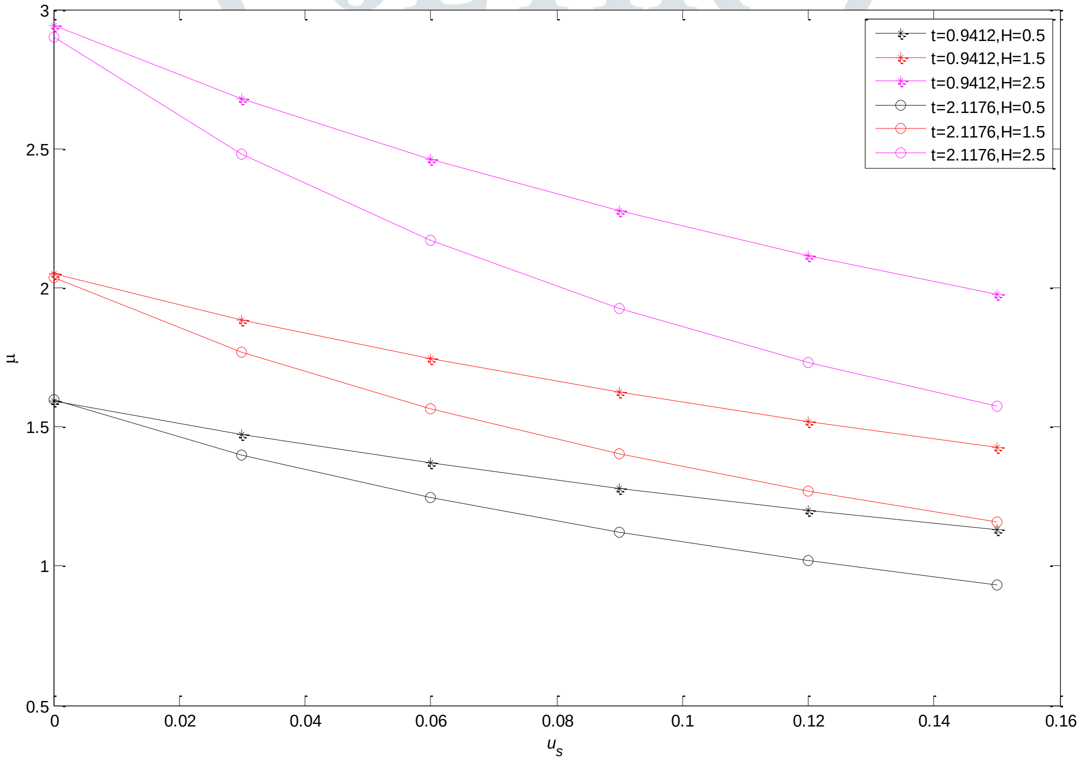

Figure13: variation of effective viscosity w.r.t slip velocity u_s for different values of H

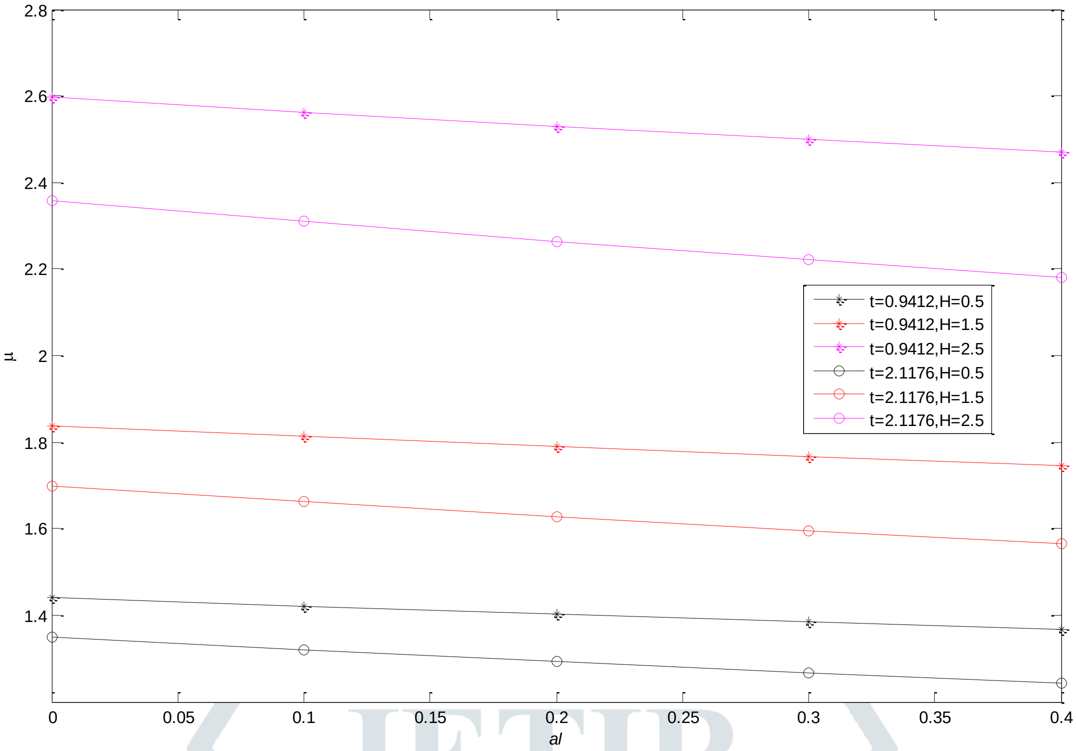

Figure 14: variation of effective viscosity w.r.t inclination angle *al* for different values of H

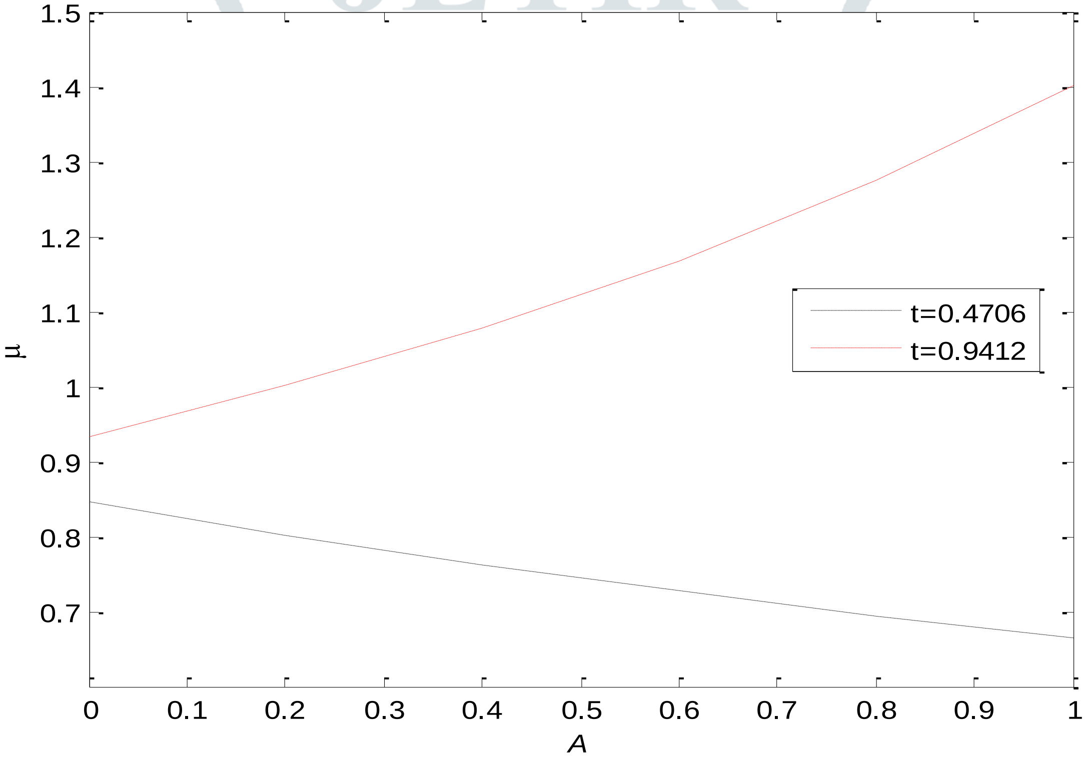

Figure15: variation of effective viscosity w.r.t body acceleration parameter *A* for different values of H

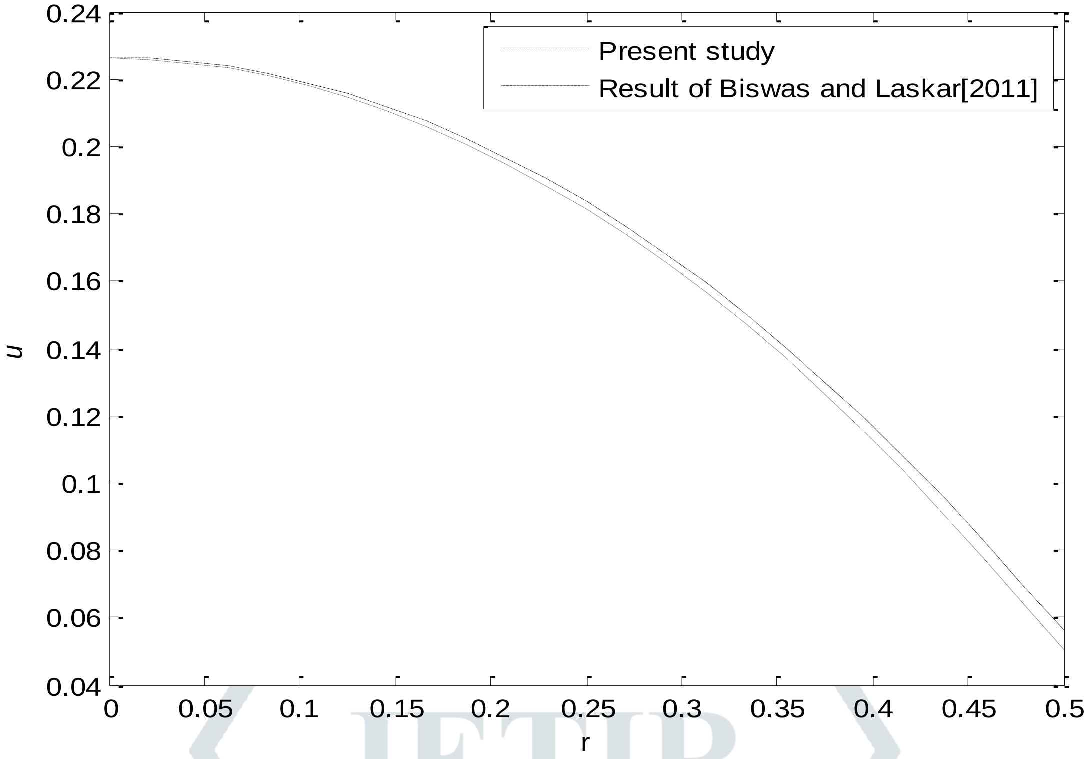

Figure16: comparison of axial velocity with result of Biswas and Laskar [2011]

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