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Squeezing Flow Of A Viscous Fluid Between Two Porous Disks

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Abstract

Squeezing flow of a viscous fluid between two parallel porous disks is investigated. The flow between the disks is governed by Navier-Stokes equations. The flow is analyzed for the following two cases: Squeeze film flow without inertia and Squeeze film flow with inertia. The velocity, the squeeze film force and the pressure distribution are numerically evaluated for different values of physical parameters of interest. The effect of inertia on the flow behavior is discussed. When the permeability $K \rightarrow 0$, the results agree with the corresponding ones of Kuzma [4]. It is found that the radial velocity is increasing with the increasing permeability parameter β and the opposite behavior is noticed for axial velocity. Further it is observed that the inertia force of flow enhances the pressure between the porous disks.

Keywords: Squeezing flow; Viscous Fluid; Porous Disks.

1. Introduction

Squeeze film flow between two disks is a simple but fundamental one and hence many works have been done on flows involving disks under various configurations. The squeeze film lubrication phenomenon is observed in several applications such as gears, bearings, machine tools, rolling elements and automotive engines. The squeeze film action is also seen during approach of faces of disk clutches under lubricated conditions. The earliest study on squeezing flow invoking lubrication approach has been presented by Stefan [1]. Langlois [2] presented an analysis for isothermal squeeze films. The problem of the squeezing of a film of liquid between two parallel surfaces is studied by Jackson [3]. Neglecting inertial effects, he deduced approximate expressions for the instantaneous distributions of velocity within the fluid and the reaction on the surface. Kuzma [4] presented experimental and theoretical results with inertia and made a comparison between them. The unsteady flow between two parallel disks with arbitrary varying gap width was studied by Ishizawa [5]. He has shown that the angular velocities of the disks are time dependent.

Nomenclature

U the average velocity

$\varepsilon = \frac{R}{h_0}$ the aspect ratio

$R_e = \frac{Uh_0}{\nu}$ the Reynolds number

Da the Darcy number

α the slip parameter

β the permeability parameter

F the force acting on the disks

H the distance between the disks

h_∞ the buoyant equilibrium height

h_0 the initial displacement

A_c the area of the container

C_p the pressure co-efficient

f the radial velocity

u_z the axial velocity

u the squeezing flow velocity

Squeezing flow results have been obtained through experiments for four different fluids in steady shear flow by Philip Leider [6]. The results are correlated using the fluid parameters obtained from steady shearing flow, the applied force, geometric variables and time required for the disk separation to reach one-half its initial value. Jones et al. [7] studied the motion of a film of liquid squeezed between a fixed and a uniformly moving plane. Grimm [8] studied the flow behaviour of thin Newtonian liquid films being squeezed between two flat plates. Bhattacharyya et al. [9] studied the unsteady motion of a viscous, incompressible and electrically conducting fluid squeezed between two parallel disks, in which the lower disk is rotating with an arbitrary time-dependent angular velocity, while the upper disk approaches the lower one with a time-dependent velocity. The extrusion of a yield stress fluid from the space between two parallel plates is investigated experimentally by Zwick et al. [10]. Lawal [11] studied polymer processing operations such as compression molding, sheet forming and injection molding which can be modeled by squeezing flows between two approaching parallel surfaces in relative motion.

Walicki et al. [12] studied a squeeze flow of a visco plastic fluid through a narrow clearance between two coaxial surfaces of revolution. Reznik et al. [13] studied strong squeezing of a two dimensional liquid droplet between parallel plates. Xuchun-hui et al. [14] studied the normal viscous forces of squeeze flow of second order fluid between two arbitrary rigid spheres. Siddiqui et al. [15] analyzed the unsteady two dimensional flow of a viscous MHD fluid flow between two parallel infinite plates. The two infinite plates are considered to be approaching each other symmetrically, causing the squeezing flow. Naduvinamani et al. [16] presented a theoretical analysis of the effects of couple stresses on the squeeze film lubrication between circular stepped plates. Sikkiru Adigun Sanni [17] investigated the effects of convective inertia on the lubricating characteristics of the squeeze film between parallel rectangular plates. Islam et al. [18] studied a steady axisymmetric MHD flow of two dimensional incompressible squeezing fluid under the influence of a uniform transverse magnetic field. Ahmed and Kalita [19] studied transient MHD free convection from an infinite vertical porous plate in a rotating system with mass transfer and Hall current. Sivaraj and Rushi Kumar [20] have studied chemically reacting dusty viscoelastic fluid flow in an irregular channel with convective boundary. Satyanaraya et al. [21] studied effects of all current and radiation absorption on MHD micropolar fluid in a rotating system. Bhaskara Reddy et al. [22] studied the flow of a Jeffrey fluid between torsionally oscillating disks. Oahimire and Olajuwon [23] studied the effect of hall current and thermal radiation on heat and mass transfer of a chemically reacting MHD flow of a micropolar fluid through a porous medium

In this paper, the squeezing flow between two parallel permeable disks is studied in two cases. One is steady squeeze film flow without inertia and the other is steady squeeze film flow with inertia. The velocity, the squeeze film force on the disks and the pressure distribution are numerically evaluated for different values of physical parameters.

2. Mathematical Formulation

Consider the flow of a fluid in the gap between two parallel permeable disks separated by a distance 2h. The gap is completely filled by incompressible viscous fluid. The gravity is assumed to be negligible. The permeability of the disks is taken as k. Cylindrical coordinate system (r, θ, z) is used with z-axis coinciding with the symmetry axis of the flow. The two disks are defined by $z = -h(t)$ and $z = h(t)$. The radius of either of the two disks R is assumed to be very much greater than half width of gap between the two disks. The flow is assumed to be primarily in r-direction. Further let $u_r << u_z$ and $\frac{\partial u_r}{\partial r} << \frac{\partial u_r}{\partial z}$. Consistent with the quasi-steady state approximation, we take $\rho \frac{\partial u_r}{\partial t} << \mu \frac{\partial^2 u_r}{\partial z^2}$. Due to the symmetry, we discuss the flow in the half of the region between the two permeable disks.

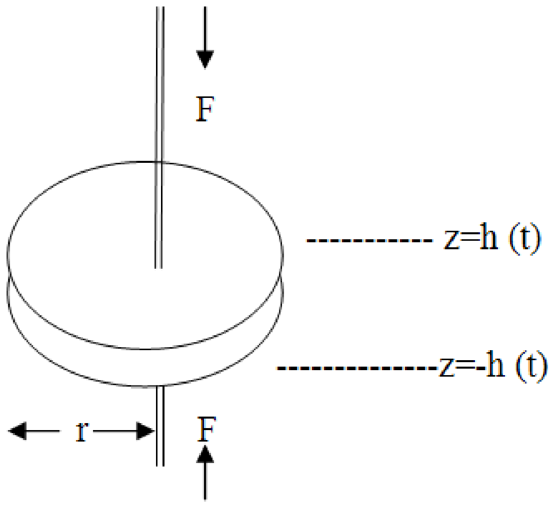

Fig. 1 Physical model

2.1 Section A: Squeezing flow without inertia

In this part, the squeezing flow of a fluid between two parallel discks in the absence of inertia is considered. The equation of continuity and equations of motion became

$$\frac{1}{r}\frac{\partial}{\partial r}\left(ru_r\right)+\frac{\partial u_z}{\partial z}=0 \tag{1}$$

$$-\frac{\partial p}{\partial r}+\mu\frac{\partial^2 u_r}{\partial z^2}=0 \tag{2}$$

$$-\frac{\partial p}{\partial z}=0 \tag{3}$$

where $u_r = u_r\left(r,z,t\right)$ and $u_z = u_z\left(z,t\right)$

It is convenient to introduce the non-dimensional quantities

$$u_r^* = \frac{u_r}{U},\ u_z^* = \frac{u_z}{U},\ p^* = \frac{p}{\rho U^2},\ r^* = \frac{r}{R},\ z^* = \frac{z}{h_0},\ h^* = \frac{\dot{h}}{U},\ H = \frac{h}{h_0} \tag{4}$$

In view of the above non-dimensional quantities, the basic equations (1) to (3) can be expressed in non-dimensional form, dropping asterisks, as

$$\frac{1}{r}\frac{\partial}{\partial r}\left(ru_r\right)+\varepsilon\frac{\partial u_z}{\partial z}=0 \tag{5}$$

$$\frac{\varepsilon}{R_e}\frac{\partial^2 u_r}{\partial z^2}-\frac{\partial p}{\partial r}=0 \tag{6}$$

$$-\frac{\partial p}{\partial z}=0 \tag{7}$$

The boundary conditions at the permeable disks are

$$\frac{\partial u_r}{\partial z}=0 \ \ at\ z=0 \ \ u_r=-\beta\frac{\partial u_r}{\partial z} \ \ at\ z=H$$

$$u_z = 0\, at\, z = 0 \quad u_z = \dot{h} - \beta \frac{\partial u_z}{\partial z} \quad at\, z = H \tag{8}$$

where $\beta = \frac{\sqrt{k}}{h_0 \alpha} = \frac{\sqrt{Da}}{\alpha}$.

2.1.1 Solution of the problem

The continuity equation then demands that $u_r = rf(z,t)$. Furthermore, the equations of motion show that p must have the form $p = p_0 + p_2 r^2$

Where p_0 and p_2 are constants to be determined. With these simplifications equation (7) is satisfied and (5) and (6) gives

$$2f + \varepsilon \frac{\partial u_z}{\partial z} = 0 \tag{9}$$

$$-2p_2 + \frac{\varepsilon}{R_e} \frac{\partial^2 f}{\partial z^2} = 0 \tag{10}$$

The boundary conditions (8) can be expressed as

$$\frac{\partial f}{\partial z} = 0 \quad at\, z = 0, \quad f = -\beta \frac{\partial f}{\partial z} \quad at\, z = H,$$

$$u_z = 0 \quad at\, z = 0 \quad u_z = \dot{h} - \beta \frac{\partial u_z}{\partial z} \quad at\, z = H \tag{11}$$

$$p = p_a \quad at\, r = 1$$

Here '$\dot{h}$' stands for $\frac{dh}{dt}$. These five conditions suffice to determine p_0, p_2 and the three constants of integration of equations (9) and (10).

The solution is

$$u_r = \frac{\dot{h}r}{s}\left[z^2 - 2\beta H - H^2\right] \tag{12}$$

$$u_z = \frac{\dot{h}}{s}\left[4\beta \frac{h}{\varepsilon} z + 2\frac{H^2}{\varepsilon} z - \frac{2}{3}\frac{z^3}{\varepsilon}\right] \tag{13}$$

$$p - p_a = \frac{\varepsilon \dot{h}}{sR_e}\left(r^2 - 1\right) \tag{14}$$

where $s = \frac{4}{3}\frac{H^3}{\varepsilon} + 4\beta \frac{H^2}{\varepsilon} + 4\beta^2 \frac{H}{\varepsilon}$

To calculate the force on one plate all we need is the pressure distribution in (14), since $\tau_{zz} = 0$ on the plates. Consequently we find

$$F = \int_0^{2\pi}\int_0^1 \left(p - p_a + \tau_{zz}\right) r\, dr\, d\theta \quad at\, z = H$$

$$= 2\pi \frac{\varepsilon \dot{h}}{sR_e} \int_0^1 \left(r^3 - r\right) dr$$

$$= -\frac{\pi \varepsilon \dot{h}}{2sR_e} \qquad (15)$$

This shows how much force F(t) must be applied in order to maintain the disk motion h(t).

If we now ask what the disk motion will be for a constant applied force F, we have to solve the differential equation for h (t) in equation (15) to give

$$h - h_0 = \frac{-2sR_e Ft}{\pi \varepsilon}$$

2.2 Section B: Squeezing flow with inertia

In this part, the squeezing flow of incompressible viscous fluid between permeable discks is considered in the presence of intertia effects.The governing equations of motion reduce to

$$\frac{\partial^2 u}{\partial z^2} = \frac{1}{\mu}\frac{\partial p}{\partial r} + \frac{\rho}{\mu}\left(\frac{\partial u_r}{\partial t} + u_r \frac{\partial u_r}{\partial r} + u_z \frac{\partial u_r}{\partial z}\right) - \left(\frac{\partial^2 u_r}{\partial r^2} + \frac{1}{r}\frac{\partial u_r}{\partial r} - \frac{u_r}{r^2}\right) \qquad (16)$$

where u_r, u_z are radial and axial velocities in the absence of inertia effects and u is the radial velocity in the presence of inertia effects.

The non dimensional forms are

$$\left.\begin{array}{llll} u^* = \dfrac{u}{U}, & p^* = \dfrac{p}{\rho u^2}, & u_r^* = \dfrac{u_r}{U}, & v_z^* = \dfrac{u_z}{U} \\ z^* = \dfrac{z}{h_0}, & r^* = \dfrac{r}{R}, & & t^* = \dfrac{Ut}{h_0} \end{array}\right\} \qquad (17)$$

Using (17) in (16), we get

$$\frac{\partial^2 u}{\partial z^2} = \frac{R_e}{\varepsilon}\frac{\partial p}{\partial r} + R_e\left[\frac{\partial u_r}{\partial t} + \frac{u_r}{\varepsilon}\frac{\partial u_r}{\partial r} + v_z \frac{\partial u_r}{\partial z} + \right] - \frac{1}{\varepsilon^2}\left[\frac{\partial^2 u_r}{\partial r^2} + \frac{1}{r}\frac{\partial u_r}{\partial r} - \frac{u_r}{r^2}\right] \qquad (18)$$

2.2.1 Solution of the problem

From the section (2.1.1), the expressions for radial and axial velocities in the absence of inertia effects are given by

$$u_r = \frac{\dot{h}r}{s}\left[z^2 - 2\beta H - H^2\right]$$

$$u_z = \frac{\dot{h}}{s}\left[4\beta \frac{H}{\varepsilon} z + \frac{2H^2}{\varepsilon} z - \frac{2}{3}\frac{z^3}{\varepsilon}\right]$$

Substituting the above equations in (18), we get

$$\frac{\partial^2 u}{\partial z^2} = \frac{R_e}{\varepsilon}\frac{\partial p}{\partial r} + R_e \frac{\ddot{h}r}{s}\left[z^2 - 2\beta H - H^2\right] + R_e \frac{\dot{h}^2 r}{s^2 \varepsilon}\left[-\frac{1}{3}z^4 + 4\beta^2 H^2 + H^4 + 4\beta H z^2 + 4\beta H^3 + 2H^2 z^2\right] \quad (19)$$

The boundary conditions are

$$\frac{\partial u}{\partial z} = 0 \quad at\; z = 0 \quad (20)$$

$$u = -\beta \frac{\partial u}{\partial z} \quad at\; z = H \quad (21)$$

Solving (19) subject to the boundary conditions (20), (21), we get

$$u = \frac{R_e}{\varepsilon}\frac{\partial p}{\partial r}\left[\frac{z^2}{2} - \frac{H^2}{2} - \beta H\right] + R_e \frac{\ddot{h}r}{s}\left[\frac{z^4}{12} - \beta H z^2 - \frac{H^2 z^2}{2} + \frac{5}{3}\beta H^3 + 2\beta^2 H^2 + \frac{5}{12}H^4\right] + \frac{R_e \dot{h}^2 r}{s^2 \varepsilon}\left[-\frac{z^6}{90} + 2\beta^2 H^2 z^2 + \frac{H^4 z^2}{2} + \frac{1}{3}\beta H z^4 + 2\beta H^3 z^2 + \frac{1}{6}H^2 z^4 - \frac{59}{60}H^6 - \frac{59}{15}\beta H^5 - \frac{22}{3}\beta^2 H^4 - 4\beta^3 H^3\right] \quad (22)$$

From the continuity equation

$$\int_0^H u\,dz = \frac{-r\dot{h}}{2} \quad (23)$$

Substituting equation (22) in (23), we get

$$\frac{\partial p}{\partial r} = \frac{\varepsilon \dot{h}}{2R_e A_1} r + \frac{\varepsilon}{\alpha}\frac{A_2}{A_1}\ddot{h} r - \frac{\dot{h}^2}{\alpha^2}\frac{A_3}{A_1} r \quad (24)$$

where $A_1 = \frac{H^3}{3} + \beta H^2$

$$A_2 = \frac{4}{15}H^5 + \frac{4}{3}\beta H^4 + 2\beta^2 H^3$$

$$A_3 = \frac{144}{315}H^7 + \frac{16}{5}\beta H^6 + \frac{20}{3}\beta^2 H^5 + 4\beta^3 H^4$$

The boundary condition on pressure is

$$p = p_a \; at\; r = 1 \quad (25)$$

Solving the equation (24) using the boundary condition (25), we get

$$p - p_a = \left[\frac{\varepsilon \dot{h}}{4R_e A_1} + \frac{\varepsilon A_2}{2sA_1}\ddot{h} - \frac{\dot{h}^2}{2s^2}\frac{A_3}{A_1}\right]\left(r^2 - 1\right) \quad (26)$$

The squeeze film force F_s then becomes

$$F_s = \int_0^1 2\pi r\left(p - p_a\right)dr \quad (27)$$

From the equation (27), we get

$$F_s = -\frac{\pi\varepsilon\dot{h}}{8R_e A_1} - \frac{\pi\varepsilon A_2}{4sA_1}\ddot{h} + \frac{\pi A_2}{4s^2 A_1}\dot{h}^2 \tag{28}$$

The equation of motion of the upper disk is given by

$$\frac{w}{g}\ddot{h} = F_s + F_b \tag{29}$$

where w is the total load including the weight of the top disk and F_b is the buoyant force acting on the disk.
The buoyant force is given by

$$F_b = \rho g \frac{AA_c}{A_c - A}\left(h_\infty - h\right) \tag{30}$$

It is convenient to introduce the non-dimensional quantities

$$w^* = \frac{w}{\rho h_0^3 g},\ A^* = \frac{A}{h_0^2},\ h^* = \frac{h}{h_0},\ F_s^* = \frac{F_s}{\rho h_0^3 g},\ F_b^* = \frac{F_b}{\rho h_0^3 g} \tag{31}$$

Using the non-dimensional quantities (31) in equations (29) and (30), dropping asterisks, as

$$w\ddot{h} = F_s + F_b \tag{32}$$

$$F_b = \frac{AA_c}{A_c - A}(h_\infty - h) \tag{33}$$

Using the equations (33) and (28) in equation(32), we get

$$\left(w + \frac{\pi\varepsilon A_2}{4sA_1}\right)\ddot{h} = \frac{\pi A_2}{4s^2 A_1}\dot{h}^2 - \frac{\pi\varepsilon\dot{h}}{8R_e A_1} + \frac{AA_c}{A_c - A}\left(h_\infty - h\right) \tag{34}$$

The boundary conditions on h are

$$h(0) = h_0, \qquad \dot{h}(0) = 0 \tag{35}$$

Equation (34) is solved by Taylor series method using the boundary condition (35), we get

$$h = \frac{AA_c}{A - A_c}\left(\frac{h_\infty - h_0}{w + \dfrac{\pi\varepsilon A_2}{4sA_1}}\right)t^2 + h_0 \tag{36}$$

To evaluate numerically this problem, we take a time increment t as 0.1 sec.

3. Results and discursion

In this paper, the squeezing flow of a viscous fluid between two permeable disks is studied and the results are discussed for various physical parameters. Flow solutions are depicted graphically for Reynolds number R_e, force F acting on the disks, aspect ratio ε, distance between the disks h, the buoyant equilibrium height h_∞, the initial displacement h_0, the area of the container A_c, the load including the weight of the top plate w. Figures 2 to 8 are drawn for the squeezing flow without inertia and Figures 9 to 11 are drawn for the squeezing flow with inertia.

Figures 2, 3 and 4 are plotted to see the influence of force F, Reynolds number R_e and permeability parameter (including the slip) β on the radial velocity for fixed values of ε and h. It is observed that the radial velocity is increasing with the increasing force F or Reynolds number R_e or permeability parameter β and the maximum velocity occurs at the center of region between the disks.

Figures 5, 6 and 7 are plotted to find the influence of force F, Reynolds number R_e and permeability parameter (including the slip) β acting on the disks on axial velocity uz for fixed values of ε and h. It is shown that the axial velocity is decreasing with the increasing F or R_e or β in the upper of the region.

Figure 8 is plotted to find the influence of force F acting on the disk on the pressure distribution Cp for fixed values of β, h, R_e and ε. It is observed that the pressure distribution is increasing with increase of force acting on the disk. The maximum pressure occurs at the midway between the two disks.

Figure 9 is sketched to see the influence of equilibrium height h_∞ on squeezing flow velocity u for fixed values of β, h, ε, r, R_e, Ac, w and h0. It is shown that the squeezing flow velocity u is increasing with the decrease of equilibrium height h_∞. Here also the maximum velocity occurs at the midway between the two disks.

Figure 10 is plotted to see the effect of Reynolds number Re on squeezing flow velocity u for fixed values of β, h, ε, r, h_∞, A_c, w and h_0. It is observed that the squeezing flow velocity u is increasing with the decrease of Reynolds number R_e in the middle region and opposite phenomena occurs in the regions which are near to the disks. Figure 11 is sketched to find the influence of Reynolds number Re on the pressure distribution for fixed values of ε, h and β. It is shown that pressure is increasing with the decrease of Reynolds number R_e.

Figure 12 is plotted to find the effect of inertia on pressure distribution for fixed values of β, h, f, R_e and ε. It is observed that pressure in the case of squeezing flow without inertia is greater than that pressure in the case of squeezing flow with inertia.

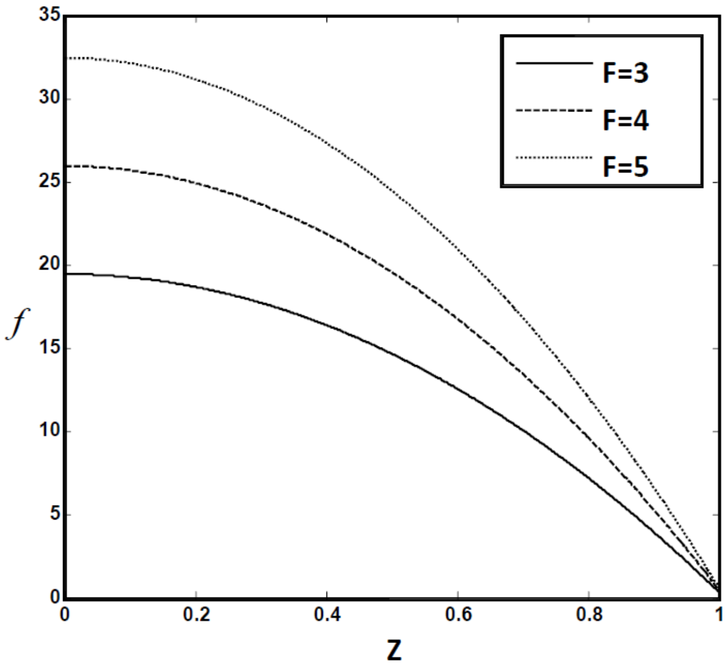

Figure 2: Variation of radial velocity f with force F acting on the disks for fixed values of β=0.01, ε=0.1, Re=1 and h=1.

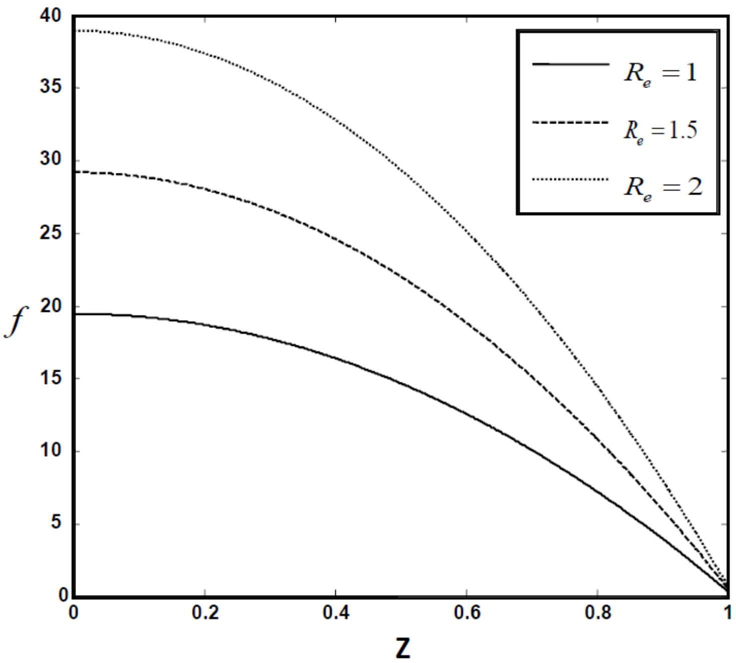

Figure 3: Variation of radial velocity f with Reynolds number Re for fixed values of β=0.01, ε=0.1, f=3 and h=1.

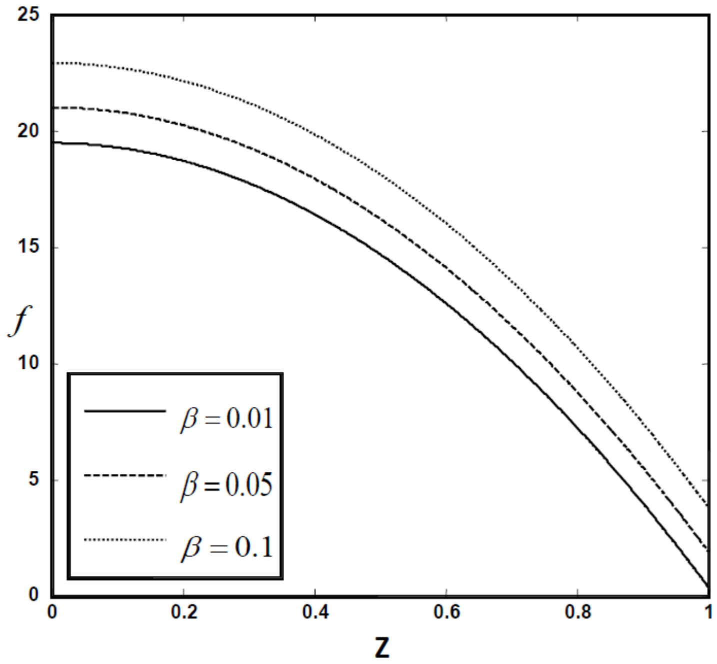

Figure 4: Variation of radial velocity f with permeability parameter β for fixed values of h=1, Re=1, ε=0.1 and F=3.

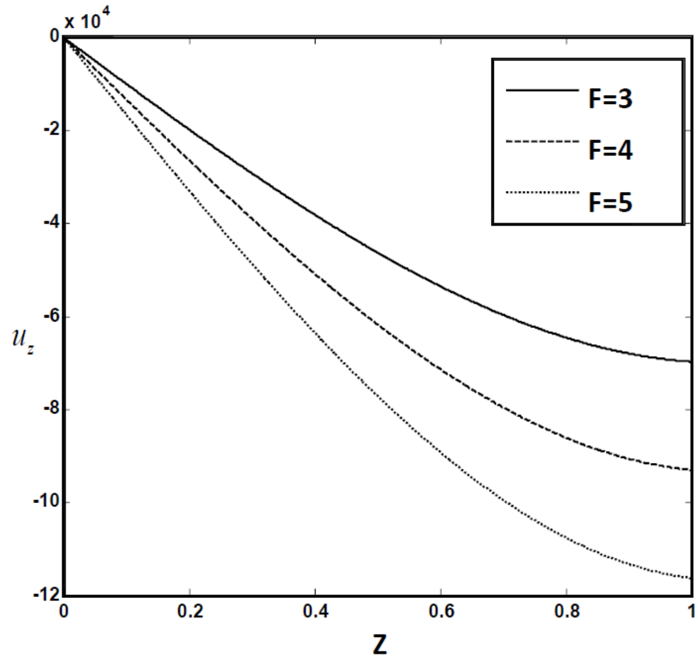

Figure 5: Variation of axial velocity uz with force F acting on the disk for fixed values of β=0.05, Re=1, ε=0.1 and h=1.

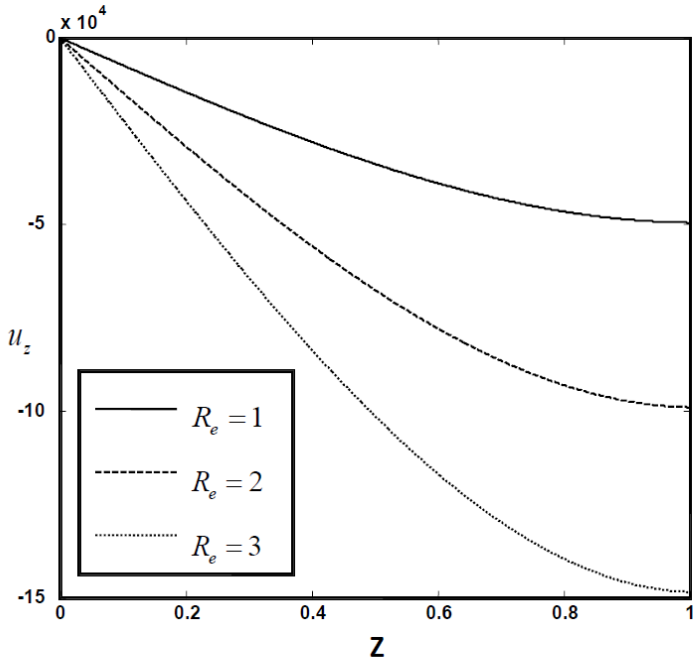

Figure 6: Variation of axial velocity uz with Reynolds number Re for fixed values of β=0.01, h=1, ε=0.1 and F=3.

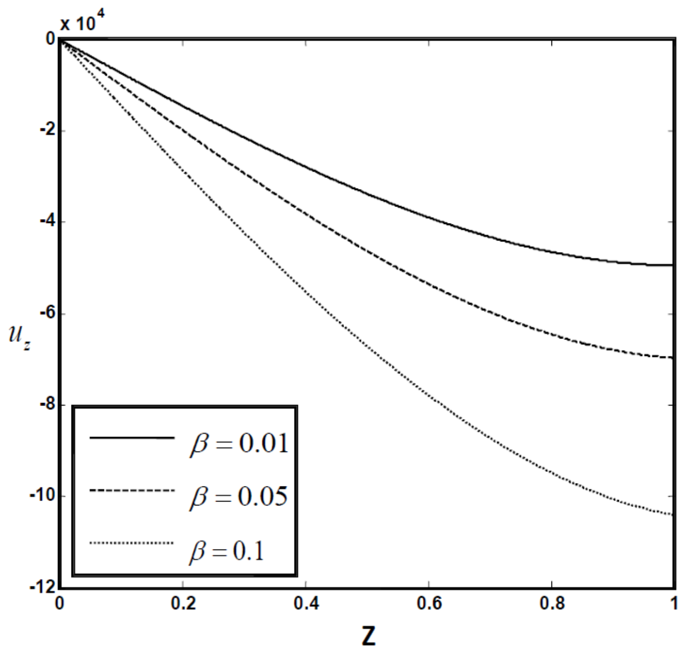

Figure 7: Variation of axial velocity uz with permeability parameter β for fixed values of h=1, Re=1, F=3 and ε=0.1.

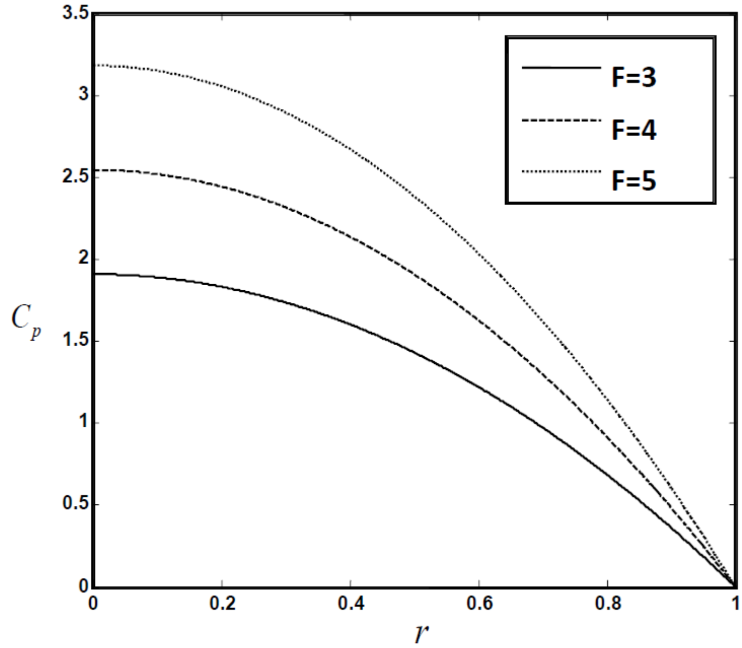

Figure 8: Variation of pressure distribution Cp with force F acting on the disks for fixed values of β=0.01, h=1, Re=1 and ε=0.

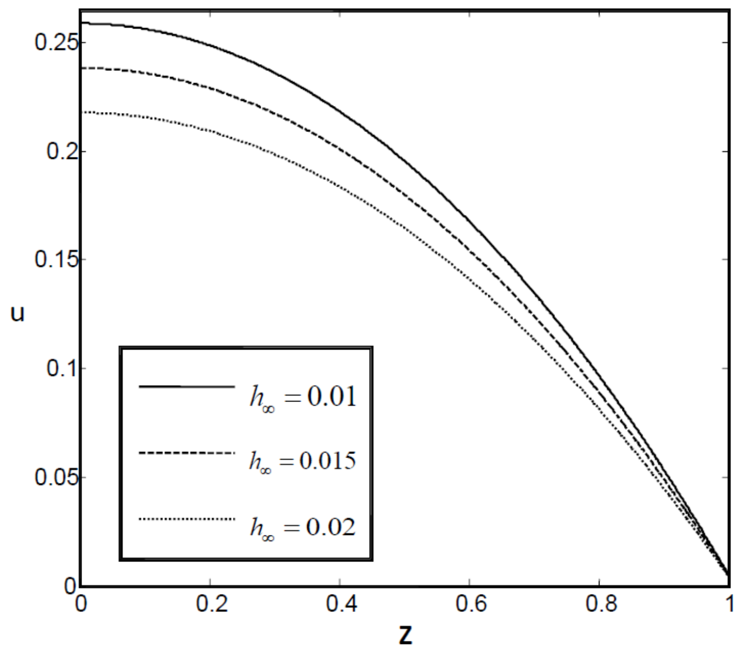

Figure 9: Variation of squeezing flow velocity u with the equilibrium height h∞ for fixed values of β=0.01, h=1, ε=0.1, r=2, Re=0.1, Ac=13, w=27.51 and h_0=0.073.

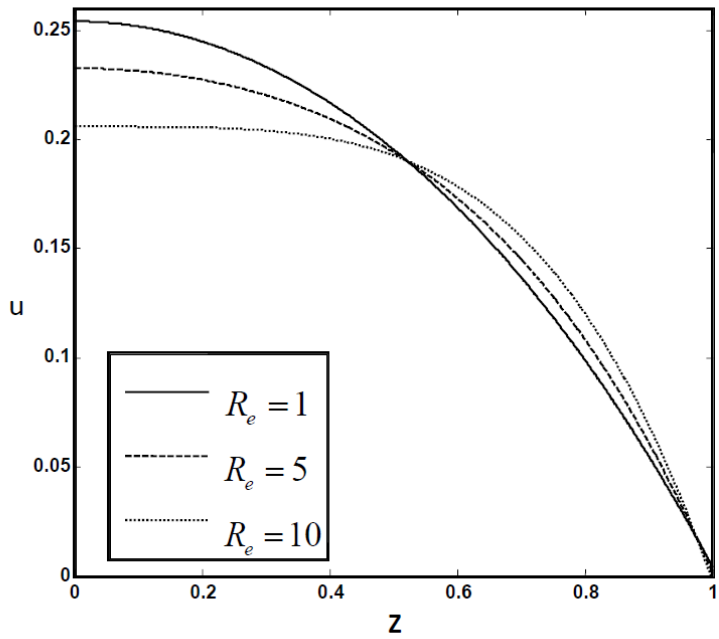

Figure 10: Variation of squeezing flow velocity u with the Reynolds number Re for fixed values of β=0.01, h=1, ε=0.1, r =2, Ac=13, h_∞=0.01, w=27.51 and h_0=0.073.

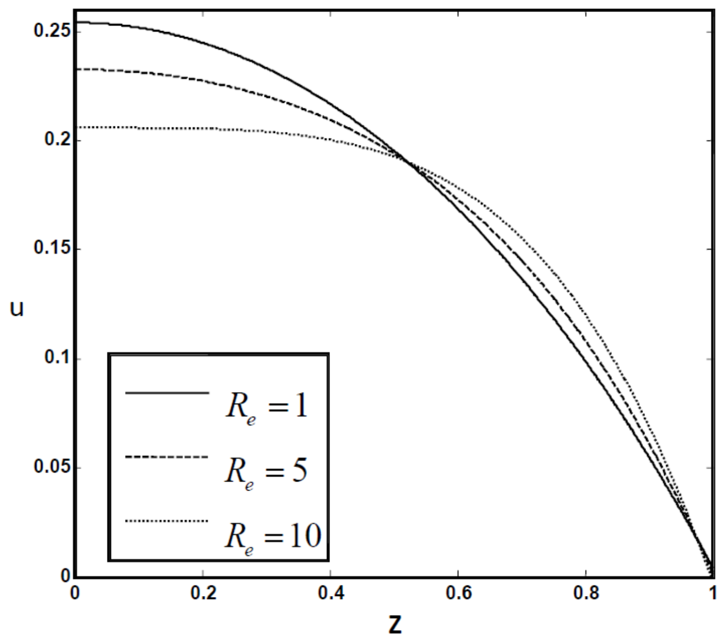

Figure 11: Variation of pressure co-efficient Cp with Reynolds number Re for fixed values of ε=0.1, h=1 and β=0.01 and h_∞=0.01.

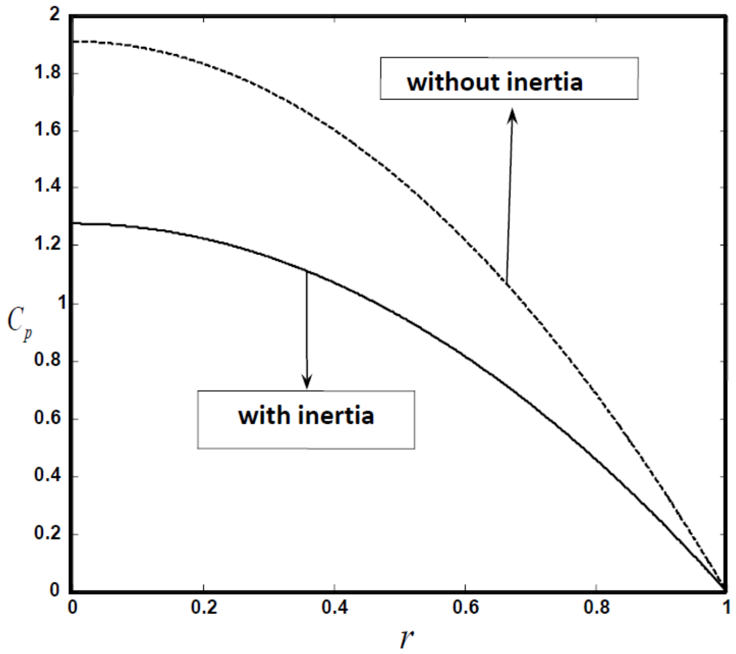

Figure 12: Variation of pressure co-efficient C_p with inertia and without inertia for fixed values of β=0.01, h=1, f=3, Re=0.01 and ε=0.1.

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References

[1] Stefan, J. 1874. Versuche uber die scheinbare adhasion. Akad. Wiss. Math. Natur., Wein, 69(2), 713-735.
[2] Langlois, W.E. 1962. Isothermal squeeze films. Quartely of Applied Mathematics, 20 (2), 131-150.
[3] Jackson, J.D. 1963. A study of squeezing flow. Applied Scientific Research, 11(1), 148-152.
[4] Kuzma, D.C. 1967. Fluid inertia effects in squeeze films. Appl. Sci. Res., 18, 15-20.
[5] Ishizawa, S. 1966. The unsteady laminar flow between two parallel disks with arbitrarily varying gap width. JSME Bull., 9, 533-550.
[6] Philip Leider, J. 1974. Squeezing flow between parallel disks. Ind. Eng. Chem., Fundam., 13(4), 342-346.
[7] Jones, A.F. and Wilson, S.D.R. 1975. On the failure of Lubrication theory in squeezing flows. Journal of Lubrication technology, 97, 101-104.
[8] Grimm, R.j. 1976. Squeezing flow of Newtonian liquid films on analysis

include fluid inertia. Journal of Applied Scientific Research, 32, 149-165.
[9] Bhattacharyya, A., Pal, A., Pop, J. 1996. MHD Squeezing flow between two parallel disks. Technische mechanic, Band 16, Heft4, 309-316.
[10] Zwick, K.J., Ayyaswamy, P.S., Cohen, I.M. squeezing flow of yield stress fluids. 1997. Oscillatory enhancement of the J. Fluid Mech., 339, 77-87.
[11] Lawal, A. 1998. Squeezing flow of Viscoplastic fluid subject to wall slip. Journal of Polymer Engineering and Science, 38 (11), 1793.
[12] Walicki, E., Walicka, A. 2001. Interia effects in Squeeze flows of Viscoplastic fluids. Journal of Mechanics of composite materials, 37(4), 347-356.
[13] Reznik, S.N., Yarin, A.L. 2002. Strong squeezing flow between parallel plates leads to rolling motion at the contact line. International journal of multiphase flow, 28(6), 911-925.
[14] Xuchun-nui, Hung Wen-bin, XU Yond.2004. Squeeze flow of a second order fluid between two parallel disks or two sphere. Journal of Applied Mathematics and Mechanics, 25(9), 1057-1064.
[15] Siddiqui, A.M., Irum, S., Ansari, A.R. 2008. Unsteady Squeezing flow of a Viscous MHD fluid between parallel plates, a solution using the homotopy perturbation method. Journal of Mathematical Modelling and Analysis, 13(4), 565-576.
[16] Naduvinamani, N.B., Siddagowda, A. 2009. Squeeze film Lubrication Between Circular Stepped plates of couple stress fluid. J. of the Braz. Soc. Of Mech. Sci and Eng. 31(1), 21.
[17] Sikkiru Adigun Sanni 2010. Convective Inertia effects on the Squeeze film between rectangular parallel plates. Turk J. Phus., 34, 181-188.
[18] Islam, S, Murad Ullah, GulZaman, Idress, M. 2011. Approximate solutions to MHD Squeezing fluid flow, J. Appl. Math. And Informatics, 29(5), 1081-1096.
[19] Ahmed, N., Kalita, D. 2011. Transient MHD free convection from an infinite vertical porous plate in a rotating fluid with mass transfer and Hall current. J Energy, Heat Mass Transfer 33, 271–292.
[20] Sivaraj, R., Rushi Kumar, B. 2012. Chemically reacting dusty viscoelastic fluid flow in an irregular channel with convective boundary. Ain Shams Eng J 4, 93– 101
[21] Satyanaraya, PV., Venkateswarlu, B., Venkataramana, S. 2013. Effects of hall current and radiation absorption on MHD micropolar fluid in a rotating system. Ain Shams Engineering Journal 4, 843-854.
[22] Bhaskara Reddy, G., Sreenadh, S., Hemadri Reddy, R., Kavitha, A. 2014. Flow of a Jeffrey fluid between torsionally oscillating disks. Ain Shams Engineering Journal 2014. (article in press).
[23] Oahimire, J.L., Olajuwon, B.I. 2014. Effect of hall current and thermal radiation on heat and mass transfer of a chemically reacting MHD flow of a micropolar fluid through a porous medium. Journal of King Saud University-Engineering Sciences, 26, 112-121.