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RESEARCH ARTICLE

COMPARISON BETWEEN THE PERFORMANCE CHARACTERISTICS OF POROUS PLANE AND PARABOLIC SLIDERS IN THE PRESENCE OF TRANSVERSE MAGNETIC FIELD LUBRICATED WITH CONDUCTING LUBRICANT ADDITIVES

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ABSTRACT

A comparative study on the performance characteristics of wide porous plane and parabolic slider is investigated in this paper. The modified Reynolds equation is derived subject to Darcy's condition for porous media. The closed form expressions for pressure, load carrying capacity and frictional force, and coefficient of friction is obtained. It is found that the effect of MHD and lubricant additives in conducting fluid is to increases the load carrying capacity and frictional force in porous media for both the sliders. But as the value of porous parameter increases load carrying capacity and frictional force decreases and coefficient of friction increases. Also the effect of porosity is prominent for plane slider than in parabolic slider.

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INTRODUCTION

The concept of porous media has been widely used in industry for a long time. Porous material has been used in lubrication applications such as journal bearing, composite slider bearing. If the bearing is porous and porous medium is impregnated with oil no exterior lubrication or further lubrication is required for the life time of machine. The lubricant penetrates into the pores and remains effective throughout the bearing life. Hydrodynamic lubrication of porous metal bearing was first studied by Morgan (1957). The effect of squeeze film on porous rectangular plates has been studied by Wu (1972) Prakash and Vij (1974) studied that porosity, causes decrease in load carrying capacity of inclined slider bearing. The porosity inversely influence the bearing characteristics, but it can be overcome by numerous design and maintenance advantages. Cusano (1972) has shown that the seepage through the boundary of porous bearings may be decreased by the use of porous housings of different permeabilities to improve bearing performance. The magnetic field is an important factor in the conditioning and controlling tribological property. To avoid unexpected viscosity variation with temperature, liquid metal lubricants has received greater interest. The effect of MHD has been studied for different film shapes by many researchers such as inclined plane slider bearing Lin, *et al.* (2009), wide inclined slider bearing with an exponential profile by Lin and Lu (2010), with a power law film profile by Lin (2012), wide tapered-land slider bearing by Lin (2010) and parallel step slider bearing by Lin *et al.* (2012a). They found that the effect of MHD improves the performance characteristics of the bearings. According to recent experimental investigations base oil blended with long chained additives is found to improve lubricating properties and surface damages. Several microcontinnnum theories have been proposed Ariman *et al.* (1973) Ariman *et al.* (1974). The couplestress fluid model is one of several model that anticipated to

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portray response of characteristics of Non-Newtonian fluid. The combined effect of MHD and couplestress and surface roughness on couplestress squeeze film lubrication between porous circular stepped plates have been studied by Naduvinamani *et al.* (2012b) and found the effect of MHD increases load carrying capacity and delay time of approach. Recently Syeda Tasneem *et al.* (2015) has studied derivation of modified Reynolds equation for hydromagnetic squeeze film and its applications to rough porous rectangular plates with lubricant additives and found that squeeze film characteristics are more pronounced for rough porous rectangular plates. Syeda Tasneem *et al.* (2013) have studied hydromagnetic couplestress squeeze film lubrication of porous plates having different geometry and found that the impact of porous facing lubricated with couplestress fluid in presence of transverse magnetic field strengthen load carrying capacity. The comparison between the impact of MHD and lubricant additives on the performance characteristics of porous plane and parabolic sliders has not been studied so far. Hence the aim of the present paper is to study the relative performance between the combined effectof MHD and lubricant additives on performance characteristics of wide porous plane and parabolic sliders.

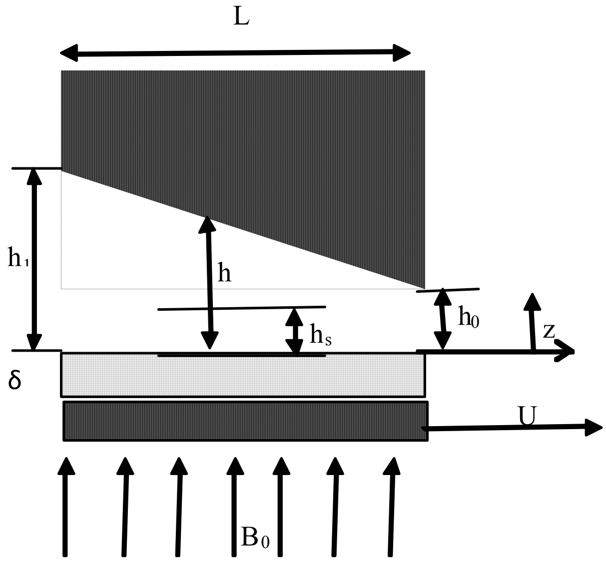

Fig.1. Geometry of Planeporous slider bearing

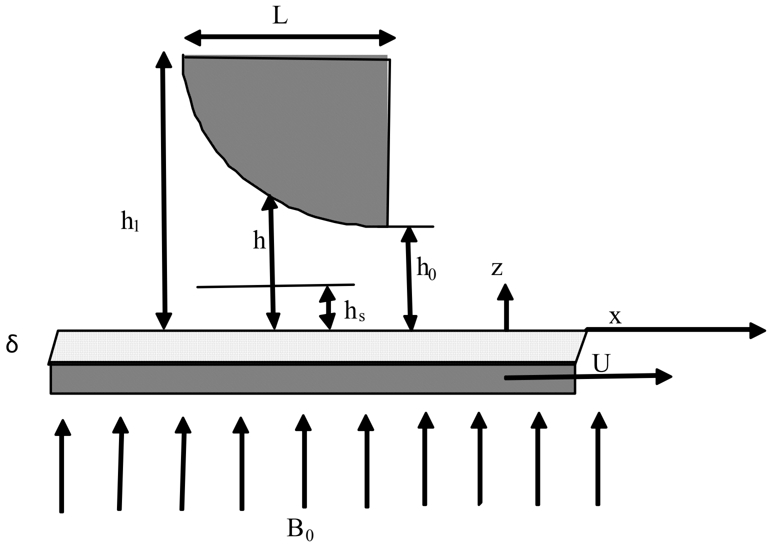

Fig. 2. Geometry of Porous parabolic slider bearing

Mathematical formulation

Fig 1 and Fig 2 represents respectively a wide porous plane and porous parabolic slider bearing lubricated with conducting fluid with lubricant additives in the presence of a magnetic field applied transversely. The bearing is of length L. The lower surface of the bearing is porous and is moving with a constant velocity U in its own plane while the upper surface is at rest. The equations governing hydro-magnetic flow with couplestress fluid as lubricant are

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0 \qquad \text{……………………………(1)}$$

$$\mu\frac{\partial^2 u}{\partial z^2}-\eta\frac{\partial^4 u}{\partial z^4}-\sigma B_0^2 u=\frac{\partial p}{\partial x}+\sigma E_y B_0 \qquad \text{……………………………(2)}$$

$$\frac{\partial p}{\partial z}=0 \qquad \text{……………………………..(3)}$$

If the bearing surfaces are perfect insulators and there is circuit external to the fluid film, then the electric field may be approximated by the requiring the net current flow to be zero.

$$\int_{y=0}^{h}\left(E_y+B_0 u\right)dz=0 \qquad \text{……………......................(4)}$$

For the porous region

$$\frac{\partial u^*}{\partial x}+\frac{\partial w^*}{\partial z}=0 \qquad \text{…………………………(5)}$$

By the modified form of Darcy's law the velocity component u^* and w^* in the porous matrix is given by

$$u^*=-\frac{k}{\mu\left(1-\beta+\frac{k\sigma B_0^2}{\mu m}\right)}\left(\frac{\partial P}{\partial x}+\sigma E_y B_0\right) \qquad \text{………………………….(6)}$$

$$w^*=-\frac{k}{\mu(1-\beta)}\frac{\partial p}{\partial z} \qquad \text{……………………………(7)}$$

For plane slider $h(x)=h_0+d(1-\frac{x}{L})$ ……………………………(8)

And for parabolic slider $h(x)=h_0+\frac{d}{L}(L-2x+\frac{x^2}{L})$ ……………………………(9)

Where $d=h_1-h_0$

The relevant boundary conditions are

At the upper surface $z=h$

$$u=0 \qquad \frac{\partial^2 u}{\partial z^2}=0 \qquad w=0 \qquad \text{……………………………(10)}$$

At the lower surface $z=0$

$$u=U \qquad \frac{\partial^2 u}{\partial z^2}=0 \qquad w=0 \qquad \text{……………………………(11)}$$

Solving equation (2) using boundary conditions (10), (11) and by using (4) we get

$$u=-\frac{h_0^2}{\mu M_0^2}\frac{\partial p}{\partial x}\frac{h}{2l}\left[\frac{A^2\left\{\frac{Sinh\frac{Bh}{l}-Sinh\frac{Bz}{l}-Sinh\frac{B(h-z)}{l}}{\left(Sinh\frac{Bh}{l}\right)}\right\}-B^2\left\{\frac{Sinh\frac{Ah}{l}-Sinh\frac{Az}{l}-Sinh\frac{A(h-z)}{l}}{\left(Sinh\frac{Ah}{l}\right)}\right\}}{\frac{A^2}{B}\tanh\frac{Bh}{2l}-\frac{B^2}{A}\tanh\frac{Ah}{2l}}\right]$$
$$+\frac{U}{2(A^2-B^2)}\left\{-B^2\left(\frac{Sinh\frac{Ah}{l}-Sinh\frac{Az}{l}+Sinh\frac{A(h-z)}{l}}{Sinh\frac{Ah}{l}}\right)+A^2\left(\frac{Sinh\frac{Bh}{l}-Sinh\frac{Bz}{l}+Sinh\frac{B(h-z)}{l}}{Sinh\frac{Bh}{l}}\right)\right\}$$

Integrating equation (1) over the film thickness and using the boundary conditions we get

$$\frac{\partial}{\partial x}\left[\left\{\left(\frac{\left(A^2-B^2\right)}{\frac{A^2}{B}\tanh\frac{Bh}{2l}-\frac{B^2}{A}\tanh\frac{Ah}{2l}}\right)\left(\frac{h_0^2h^2}{2\mu l M_0^2}+\frac{k\delta h}{2l\mu c^2}\right)-\frac{h_0^2 h}{\mu M_0^2}\right\}\frac{\partial P}{\partial x}\right]=\frac{\partial}{\partial x}\left\{\frac{Uh}{2}+\frac{k\delta M_0^2 U}{2h_0^2c^2}\right\} \qquad \text{…………..(12)}$$

By normalising the equation (12) using non-dimensional quantities

$$x^*=\frac{x}{L},\ P^*=\frac{Ph_0^2}{\mu UL},\ l^*=\frac{2l}{h_0},\ h^*=\frac{h}{h_0},\psi=\frac{k\delta}{h_0^3},\delta^*=\frac{\delta}{h_0},\ M_0=B_0h_0\left(\frac{\sigma}{\mu}\right)^{1/2} \quad h^*=\frac{h}{h_0}$$
$$where\ d^*=\frac{h_1-h_0}{h_0}$$

The modified Reynolds equation becomes

$$\frac{\partial}{\partial x^*}\left[f(h^*,l^*,M_0,\psi)\frac{\partial P^*}{\partial x^*}\right]=6\frac{\partial h^*}{\partial x^*} \qquad \text{……………………………(13)}$$

Where $f(h^*,l^*,M_0,\psi)=\frac{12h^{*2}}{l^*M_0^2}\left\{\left(\frac{\left(A^{*2}-B^{*2}\right)}{\frac{A^{*2}}{B^*}\tanh\frac{B^*h^*}{l^*}-\frac{B^{*2}}{A^*}\tanh\frac{A^*h^*}{l^*}}\right)\left(1+\frac{\psi M_0^2}{h^*c^2}\right)-\frac{l^*}{h^*}\right\}$

Integrating both sides of equation (13)w.r.to x^*

$$\left\{f^*(h^*,l^*,M_0,\psi)\frac{\partial P^*}{\partial x^*}\right\}=6h^*+C_1$$
$$\frac{\partial P^*}{\partial x^*}=\frac{6h^*}{f^*(h^*,l^*,M_0,\psi)}+\frac{C_1}{f^*(h^*,l^*,M_0,\psi)} \qquad \text{……………………………(14)}$$

Integrating both sides of equation (14) w. r. t. x^* we get

$$P^* = 6\int_{x^*=0}^{x^*} \frac{h^*}{f^*(h^*,l^*,M_0,\psi)}dx^* + C_1\int_{x^*=0}^{x^*} \frac{1}{f^*(h^*,l^*,M_0,\psi)}dx^* + C_2 \qquad \text{……………………………(15)}$$

Boundary conditions of porous region are

$P^* = 0$ at. $x^* = 0,1$

$$6\int_{x^*=0}^{1} \frac{h^*}{f^*(h^*,l^*,M_0,\psi)}dx^* + C_1\int_{x^*=0}^{1} \frac{1}{f^*(h^*,l^*,M_0,\psi)}dx^* = 0$$

$$C_1 = -\frac{6\displaystyle\int_{x^*=0}^{1} \frac{h^*}{f^*(h^*,l^*,M_0,\psi)}dx^*}{\displaystyle\int_{x^*=0}^{1} \frac{1}{f^*(h^*,l^*,M_0,\psi)}dx^*}$$

The load per unit width is given by

$$w = \int_0^L P dx$$

$$W^* = \int_{x^*=0}^{1} P^* dx^*$$

$$W^* = 6\int_0^1\int_{x^*=0}^{x^*} \frac{h^*}{f^*(h^*,l^*,M_0,\psi)}dx^*dx^* - \frac{6\displaystyle\int_{x^*=0}^{1} \frac{h^*}{f^*(h^*,l^*,M_0,\psi)}dx^*}{\displaystyle\int_{x^*=0}^{1} \frac{1}{f^*(h^*,l^*,M_0,\psi)}dx^*}\int_0^1\int_{x^*=0}^{x^*} \frac{1}{f^*(h^*,l^*,M_0,\psi)}dx^*dx^* \qquad \text{…………………………(16)}$$

The non-dimensional frictional force is

$$F^* = \int_0^1 G(h^*,l^*,M_0)dx^* + 3\int_0^1\left\{\frac{h^*}{\xi(h^*,l^*,M_0)}\right\}dx^* - 3\left\{\frac{\displaystyle\int_{x^*=0}^{1} \frac{h^*}{f^*(h^*,l^*,M_0,\psi)}dx^*}{\displaystyle\int_{x^*=0}^{1} \frac{1}{f^*(h^*,l^*,M_0,\psi)}dx^*}\right\}\int_0^1\left(\frac{1}{\xi(h^*,l^*,M_0)}\right)dx^* \qquad \text{…………………(17)}$$

Where $\xi(h^*,l^*,M_0) = \dfrac{12h^*}{l^*M_0^2}\left\{\left(\dfrac{(A^{*2}-B^{*2})}{\dfrac{A^{*2}}{B^*}\tanh\dfrac{B^*h^*}{l^*} - \dfrac{B^{*2}}{A^*}\tanh\dfrac{A^*h^*}{l^*}}\right)\left(1+\dfrac{\psi M_0^2}{h^*c^2}\right) - \dfrac{l^*}{h^*}\right\}$

The coefficient of friction

$$C = \frac{F^*}{W^*}$$

RESULTS AND DISCUSSION

The effect of MHD, Couplestress, and porosity is analysed for slider bearing with distinct film shape namely, plane and parabolic through Hartmann number M_0, couplestress parameter l^* and permeability parameter ψ respectively. M_0 Signifies the effect of magnetic field and is applied transversely, l^* signifies the effect of polar additives and permeability parameter, ψ results from the fluid which bleeds into the pores of porous matrix.

Normalized pressure

Fig 3 depicts the plots of Normalized pressure P^* against x^* for $M_0 = 0$ (non-magnetic case), $l^* = 0$ (Newtonian fluid), $l^* = 0.4$ (couplestress) and $M_0 = 5$ (magneticcase) corresponding to $d^* = 1.5, m = 0.6, \delta^* = 0.01, \beta = 0.1, \psi = 0.1$. The plots with dotted line represents pressure distribution of plane slider and with solid line denotes the pressure distribution of parabolic slider. As the value of Hartmann number increases the build-up pressure in the film region increases for both the sliders. It is observed that porous parabolic slider is having more build-up pressure than the porous inclined plane slider.

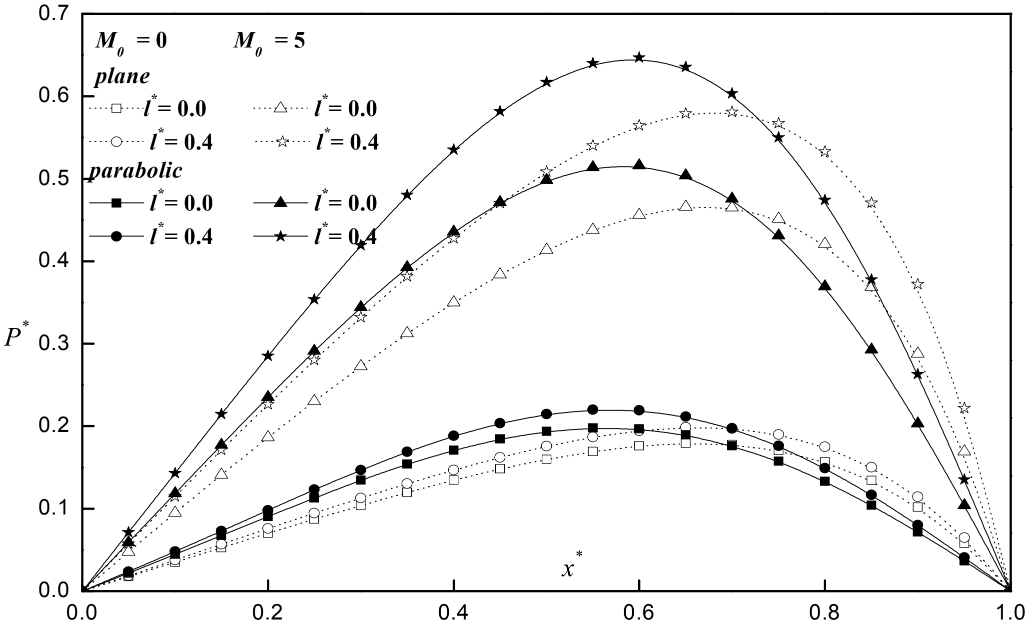

Fig. 3. Comparison of non-dimensional pressure P^* against x^* between plane and parabolic sliders for different values of l^* and M_0 with $\delta = 0.01$, $d^* = 1.5$, $\beta = 0.1, m = 0.6, \psi = 0.1$

Normalized load carrying capacity

Fig 4 corresponds to the Normalized load carrying capacity of inclined plane slider and parabolic slider represented by dotted and solid lines respectively. In the graph Normalized load carrying capacity W^* plotted against the shoulder parameter d^*. The graph is plotted for non-magnetic case ($M_0 = 0$) and magnetic case ($M_0 = 5$) and for Newtonian $\left(l^* = 0.0\right)$ and couplestress case $\left(l^* = 0.4\right)$. It is observed that as the value of M_0 and l^* increases load carrying capacity of both film shape increases. It also shows that load carrying capacity of parabolic slider is more than inclined plane slider. It is also observed from Table 1 that as the value of permeability parameter ψ increases, the load carrying capacity decreases.

Frictional force

Fig 5 represent variation of non-dimensional frictional force against the shoulder parameter d^*. The graph is plotted for non-magnetic ($M_0 = 0$) and magnetic case ($M_0 = 5$). It is visible that as the values of M_0 and l^* increases the frictional force also increases. It is observed that frictional force both parabolic and plane sliders are coinciding for smaller values of d^* but as the value of d^* increases the plane slider's frictional force is slightly on the higher side. It is also observed from Table 1 that as the value of permeability parameter ψ increases, the frictional force decreases.

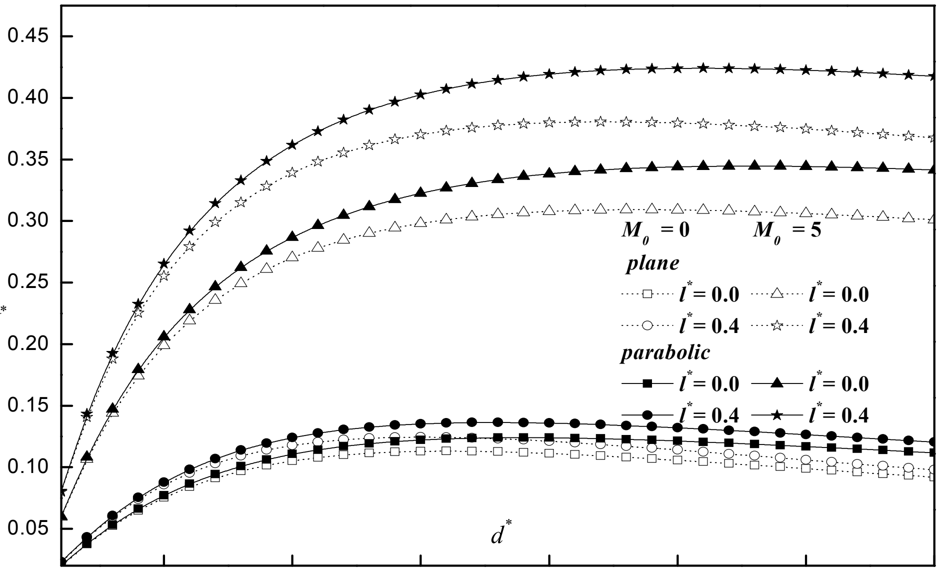

Fig. 4. Comparison of non-dimensional load W^* with d^* between plane and parabolic slidersfor different values of l^* and M_0 with $\delta = 0.01$, $d^*=1.5$, $\beta=0.1, m=0.6, \psi=0.1$

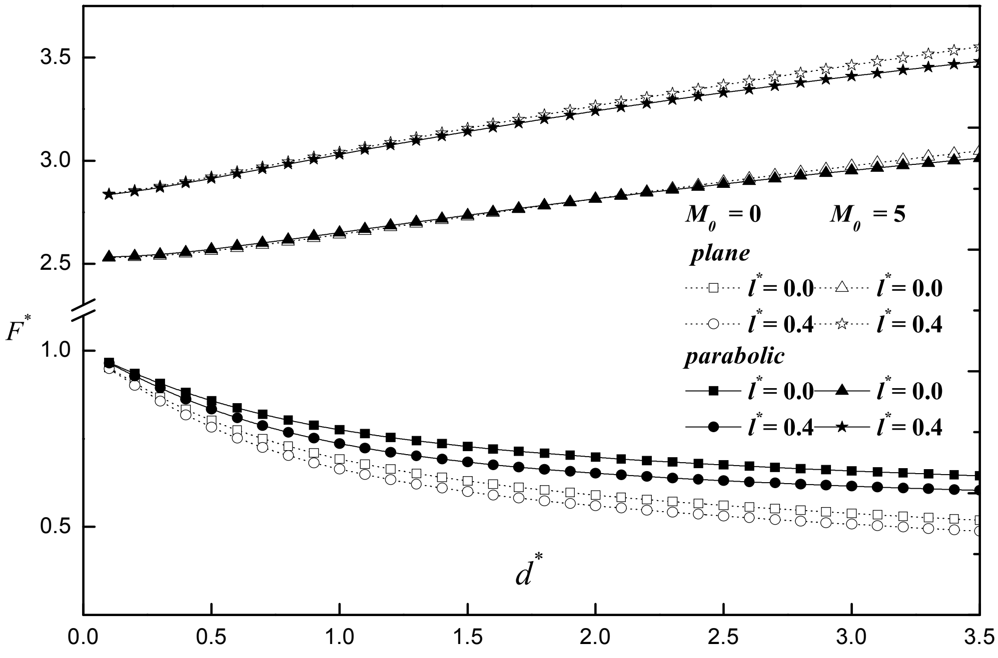

Fig. 5. Comparison of non-dimensional friction F^* with d^* between plane and parabolic slidersfor different values of l^* and M_0 with $\delta = 0.01$, $d^*=1.5$, $\beta=0.1, m=0.6, \psi=0.1$

Coefficient of friction

Fig 6 represent variation of coefficient of friction against the shoulder parameter d^*. It is observed that for increasing values of couple stress parameter l^* coefficient of friction decreases. It is observed from Table 1 that as permeability parameter ψ

increases, coefficient of friction increases. The coefficient of friction of parabolic slider is lesser than that of an inclined plane slider.

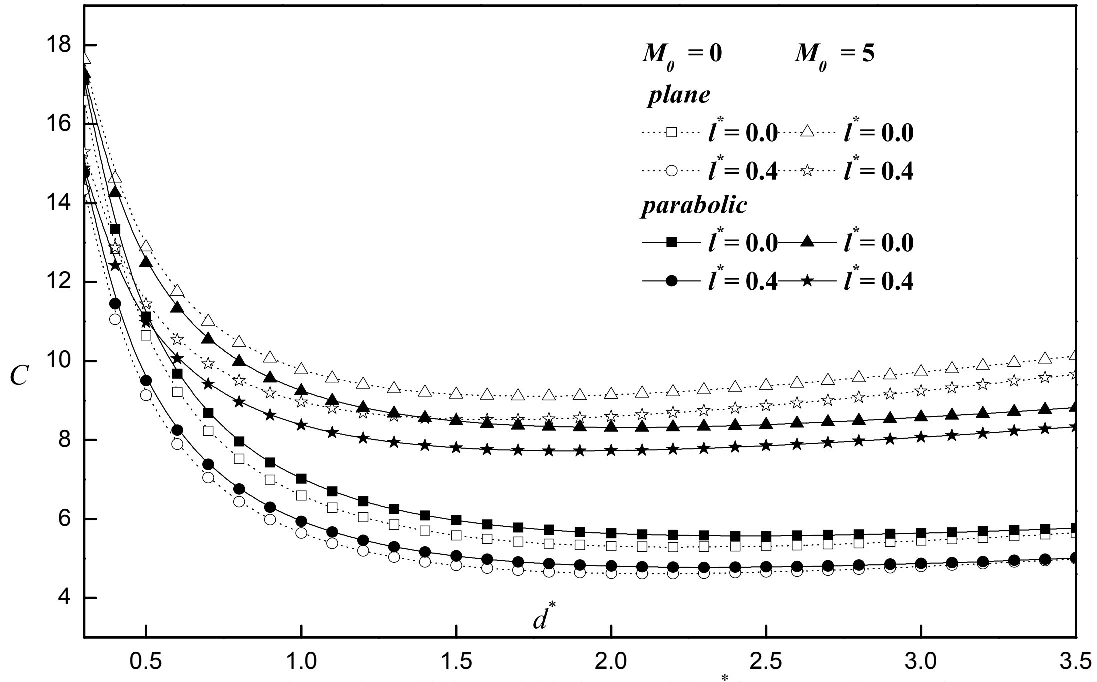

Fig. 6. Comparison of coefficient of friction C with d^* between plane and parabolic sliders for different values of l^* and M_0 with $\delta = 0.01$, $d^* = 1.5$, $\beta = 0.1$, $m = 0.6$, $\psi = 0.1$

Table-1 shows Comparison between the load carrying capacity, frictional force and coefficient of friction in case of Porous Plane and Parabolic Sliders with $\beta = 0.1,\ \delta = 0.01,\ m = 0.6,\ d^* = 1.5$

Table 1. Comparison between the load carrying capacity, frictional force and coefficient of friction in case of Porous Plane and Parabolic Sliders with $\beta = 0.1,\ \delta = 0.01,\ m = 0.6,\ d^* = 1.5$

Bearing Characteristic	**sliders**	M_0	$\psi = 0$	$\psi = 0.001$	$\psi = 0.01$	$\psi = 0.1$	$\psi = 1.0$
W^*	Plane	5	0.372464	0.370697	0.370362	0.370322	0.370318
		15	1.16372	1.15873	1.15862	1.15861	1.15861
		25	2.22984	2.22057	2.2205	2.22049	2.22049
		35	3.49889	3.48459	3.48453	3.48453	3.48453
	parabolic	5	0.405071	0.403049	0.402667	0.40262	0.402616
		15	1.25079	1.24519	1.24507	1.24506	1.24506
		25	2.39321	2.38285	2.38277	2.38276	2.38276
		35	3.75231	3.73635	3.73629	3.73628	3.73628
F^*	Plane	5	3.15937	3.15734	3.15696	3.15691	3.15691
		15	12.2201	12.2157	12.2156	12.2156	12.2156
		25	24.2964	24.2886	24.2885	24.2885	24.2885
		35	38.7889	38.777	38.777	38.777	38.777
	parabolic	5	3.14342	3.14139	3.141	3.14096	3.14095
		15	12.2299	12.2255	12.2254	12.2254	12.2254
		25	24.3045	24.2969	24.2968	24.2968	24.2968
		35	38.805	38.7934	38.7934	38.7934	38.7934
C	Plane	5	8.48233	8.51732	8.52398	8.52478	8.52487
		15	10.5009	10.5424	10.5432	10.5433	10.5433
		25	10.896	10.938	10.9383	10.9384	10.9384
		35	11.0861	11.1282	11.1283	11.1283	11.1283
	parabolic	5	7.76018	7.79406	7.8005	7.80128	7.80136
		15	9.77769	9.81817	9.81905	9.81914	9.81914
		25	10.1556	10.1966	10.1969	10.1969	10.1969
		35	10.3416	10.3827	10.3829	10.3829	10.3829

Table 2. Comparison between the Normalized relative load carrying capacity, relative frictional force and coefficient of friction with $\beta = 0.1,\ \delta = 0.01,\ m = 0.6,\ d^* = 1.5$

	sliders	M_0	R_w^*	R_f^*	R_C
$\psi = 0.001$	plane	1	5.581881	19.76003	13.42891
		3	43.27136	144.1697	70.4248
		5	100.7555	320.8345	109.6261
	parabolic	1	4.834856	15.03619	9.73099
		3	38.5494	114.926	55.12572
		5	91.81848	265.819	90.71116
$\psi = 0.01$	plane	1	9.122041	22.39295	12.1612
		3	50.35442	151.545	67.30121
		5	111.0349	333.7353	105.5274
	parabolic	1	8.813156	17.3932	7.88503
		3	46.27411	121.0204	51.10026
		5	102.8794	276.3574	85.50844
$\psi = 0.1$	plane	1	52.24021	47.78904	-2.92382
		3	111.8988	205.2406	44.05014
		5	197.5071	426.3596	76.92322
	parabolic	1	57.82306	42.60394	-9.6433
		3	114.5541	169.7738	25.73656
		5	197.677	359.4095	54.33074

The relative percentage increase in non-dimensional load R_{W^*}, non-dimensional frictional force R_{F^*} and coefficient of frictions R_C is given by

$$R_{w^*} = \{(W^*_{magnetic} - W^*_{non-magnetic}) / W^*_{magnetic}\} \times 100$$

$$R_{F^*} = \{(F^*_{magnetic} - F^*_{non-magnetic}) / F^*_{magnetic}\} \times 100$$

$$R_C = \{(C_{magnetic} - C_{non-magnetic}) / C_{magnetic}\} \times 100$$

and is evaluated for the both slider bearing and is presented in Table 2, Corresponding to $l^* = 0.4, d^* = 1.5, m = 0.6, \delta^* = 0.01, \beta = 0.1$ From the Table 2, an increase of 50.35% in load carrying capacity, 151.55% in frictional force and 67.30% is observed for inclined plane slider and an increase of 46.27% in load carrying capacity, 121.02% in frictional force and 51.10% in coefficient of friction is observed for parabolic slider corresponding to $M_0 = 3$ and $\psi = 0.01$.

Conclusion

A comparative study is made between porous inclined plane slider and parabolic slider about their performance characteristics on the application of a uniform transverse magnetic field in the presence of conducting fluid with lubricant additives.

- It is observed that effect of transverse magnetic field and lubricant additives in the conducting fluid increases the load carrying capacity and frictional force.
- As the value of couplestress parameter increases the coefficient of friction decreases.
- It is also observed as the value of permeability parameter increases load carrying capacity, frictional force decreases and coefficient of friction increases.
- It is also observed that the combined effect of MHD and conducting fluid with lubricant additives on porous parabolic film shaped slider has more prominent bearing characteristics than on inclined porous plane slider.
- The very important outcome of this paper is that the effect of porosity is prominent in parabolic slider.

Nomenclature

B_0	Applied magnetic field
C	Coefficient of friction
d	Inlet-outlet film thickness difference $(h_1 - h_0)$
d^*	Non-dimensional inlet film thickness
F	Frictional force
F^*	Non-dimensional frictional force $\left(= -Fh_0 / \mu UL\right)$
h	Film thickness
h_1	Inlet film thickness
h_0	Outlet film thickness
k	Permeability
l^*	Non-dimensional couplestress parameter
l	Couplestress parameter
L	Bearing length
M_0	Hartmann number
p	Pressure in the film region
P	Pressure in the porous region
P^*	Non-dimensional pressure
x, y	Rectangular co-ordinates
x^*	Non-dimensional rectangular coordinates $\left(= x / L\right)$
u, v	Velocity component in film region
u^*, v^*	Velocity component in porous region
w	Load carrying capacity
W^*	Non-dimensional load carrying capacity $\left(= wh_0^2 / \mu UL^2\right)$
β	Ratio of microstructure size to pore size $\left(= \left(\eta / \mu\right) / k\right)$
δ	Porous layer thickness
η	Material constant characterizing couple stress
μ	Viscosity coefficient
σ	Electrical conductivity
ψ	Permeability parameter $\left(= k\delta / h_0^2\right)$

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