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Study on Ferrofluid Bearings and their Load Capacity

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Abstract: Ferrofluids have good applications as lubricants. Rosenswieg, Shliomis and Jenkins are three important models of ferrofluid depending on the stress relation. In this paper, we study Shliomis model for hyperbolic slider bearings. Expressions for pressure and load carrying capacity are obtained. It is shown that the load carrying capacity depends on the curvature of the hyperbolic bearing along with volume concentration and Langevin's parameter.

Keywords: *Ferrofluids, Rosensweig model, Shliomis model, Jenkins model, hyperbolic slider bearing, Langevin's parameter, volume concentration.*

Mathematics Subject Classification: 76D08

1 Introduction

Ferrofluids are colloidal liquids made of nano scale ferromagnetic or ferrimagnetic particles suspended in a carrier fluid usually an organic solvent (benzene, carbon-dioxide, chloroform)or water. The carrier fluid can be classified as polar or non polar. In polar fluids body torque per unit mass is introduced in addition to the body force and a couple stress is introduced in addition to the normalstress.Whereas in non polar fluids only body force and Normal stress are introduced.Either the stress tensor is symmetric or the angular momentum is conserved in non polar fluids. In non polar ferrofluid Magnetization $\vec{M}$ is parallel to applied magnetic field $\vec{H}$ [4, 5].

Lubrication has a wide range of industrial applications. Lubricants are introduced to reduce friction and wear. Bearings are of two types contact and non contact bearings. In contact bearing there is a mechanical contact between elements and they include sliding, rolling and flexural bearings. Sliding bearing is a support for a structure that slides relative to a base structure. sliding contact bearings are used for low modest speed applications. Polymers, brass, and ceramics are commonly used materials for slider bearing. The types of slider bearings are journal bearing, pivot bearing and thrust bearing.

P. Sinha et. al[2] have studied Shliomis model for ferrofluid lubrication of cylindrical rollers with cavitation and showed that ferrofluid lubrication increases the load carrying capacity without affecting the point of cavitation. V. K. Agrawal [3] used Jenkins model for ferrofluid on porous inclined slider bearing and seen that the load capacity increases with increase in the magnetic fluid parameter. J. R. Patel et. al [6] studied Shliomis model for ferrofluid lubrication of rough porous convex pad slider bearing and observed that in spite of the adverse effect of roughness there is atleast $20-25\%$ increase in the load carrying capacity. Patel N. D. and Deheri G. M. [7] analyzed hydromagnetic lubrication of a rough porous parabolic slider bearing with slip velocity for Jenkins model for ferrofluid and established that the roughness should be considered for designing the bearing system.

In the present paper we have analyzed hyperbolic slider bearing for Shliomis model, which deals with polar ferrofluids. The paper is divided into five section, section 1 consists of introduction, section 2 consists of geometrical model and governing equations of the problem, section 3 has details of solution, section 4 contain results and discussions, and section 5 has graphs.

2 Geometry and Governing equations

The configuration of the bearing system is shown in Fig. 1.

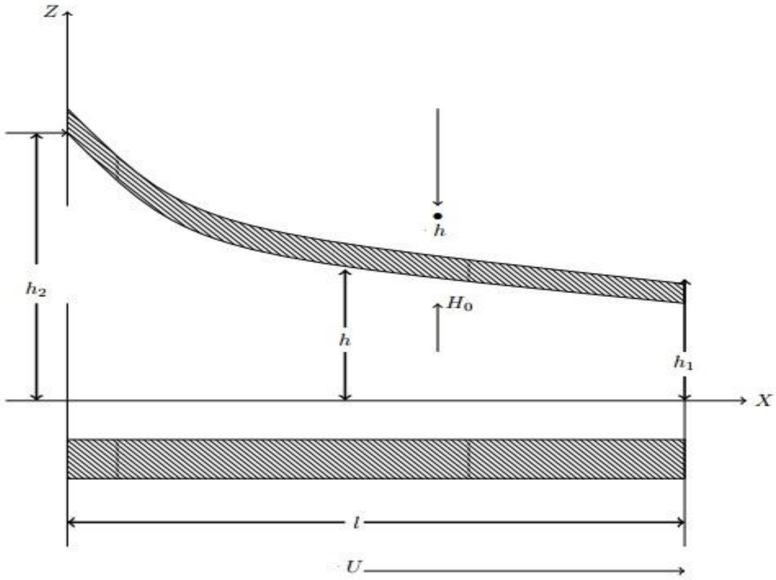

Fig. 1. Physical configuration of hyperbolic slider bearing

The hyperbolic slider bearing is moving with a uniform velocity U in the X direction and a stator is backed by a solid wall. l is the length and b is the breadth of the bearing with $l << b$. The film thickness h [9] is defined as

$$h = \frac{h_2}{1 + \frac{x \log a}{l}}, 0 \le x \le l \tag{1}$$

where $a = \frac{h_2}{h_1}$.

Consider incompressible, steady polar fluid by neglecting inertia and second derivative of the internal angular momentum $\vec{S}$. we have the following equations governing the flow [1, 5]

$$\nabla . \vec{q} = 0 \tag{2}$$

$$-\nabla \vec{p} + \eta \nabla^2 \vec{q} + \mu_0 (\vec{M} . \nabla) \vec{H} + \frac{1}{2\tau_s} \nabla \times (\vec{S} - I\vec{\Omega}) = 0, \tag{3}$$

$$\vec{\Omega} = \frac{1}{2} \nabla \times \vec{q}, \tag{4}$$

$$\vec{S} = I\vec{\Omega} + \mu_0 \tau_s (\vec{M} \times \vec{H}), \tag{5}$$

$$\vec{M} = M_0 \frac{\vec{H}}{H} + \frac{\tau_B}{I} (\vec{S} \times \vec{M}), \tag{6}$$

$$\nabla \times \vec{H} = 0, \tag{7}$$

$$\nabla.(\vec{H} + \vec{M}) = 0, \tag{8}$$

where p is the pressure, $\vec{v}$ is the fluid velocity, $\vec{S}$ is the internal angular momentum, $\vec{H}$ is the applied magnetic field, $\vec{M}$ is the Magnetization, M_0 is the equilibrium magnetization, $\vec{I}$ is the sum of the moments of inertia of the particles per unit volume, μ_0 is the permeability of free space, τ_B is the Brownian relaxation time, τ_s is the magnetic moment relaxation time, η is the viscosity of the suspension.

Using (5) in (3) and (6) we get,

$$-\nabla\vec{p} + \eta\nabla^2\vec{q} + \mu_0(\vec{M}.\nabla)\vec{H} + \frac{\mu_0}{2}\nabla\times(\vec{M}\times\vec{H}) = 0, \tag{9}$$

$$\vec{M} = M_0\frac{\vec{H}}{H} + \tau_B\vec{\Omega}\times\vec{M} - \frac{\mu_0\tau_B\tau_s}{I}\vec{M}\times(\vec{M}\times\vec{H}). \tag{10}$$

Langevin's parameter $\xi > 1$ for strong magnetic field [1], then equation (10) becomes,

$$\vec{M} = \frac{M_0}{H}[\vec{H} + \bar{\tau}(\vec{\Omega}\times\vec{H})], \tag{11}$$

where

$$\bar{\tau} = \frac{6\eta\phi}{nk_BT(1+\xi\coth\xi)}, \tag{12}$$

$$M_0 = n\mu(\coth\xi - \frac{1}{\xi}), \tag{13}$$

$$H = \frac{k_BT\xi}{\mu_0\mu}, \tag{14}$$

for a suspension of spherical particles $\frac{I}{\tau_s} = 6\eta\phi$ and $\tau_B = d\frac{3\eta V}{k_BT}$, $\phi = nV$ is the volume concentration of the particles, k_B is the Boltzmann constant, n is the number of particles per unit volume, T is the temperature and μ is the magnetic moment of a particle [1].

3 Method of Solution

Let us consider $\vec{q} = (u(z),0,0)$, $\vec{H} = (0,0, H_0)$, then equation (8)-(10) yield

$$\frac{\partial^2 u}{\partial z^2} = \frac{1}{\eta(1+\tau)}\frac{dp}{dx}, \tag{15}$$

where

$$\tau = \frac{3}{2}\phi\frac{\xi - \tanh\xi}{\xi + \tanh\xi}. \tag{16}$$

Solving equation (15) under the no slip boundary conditions $u = 0$ at $z = h$ and $u = U$ at $z = 0$ we get

$$u = \frac{1}{\eta(1+\tau)}\left(\frac{z^2 - hz}{2}\right)\frac{dp}{dx} + U\left(1 - \frac{z}{h}\right). \tag{17}$$

Integrating equation (2) we obtain

$$\frac{\partial}{\partial x}\int_0^h udz + w_h - w_0 = 0, \tag{18}$$

where $w_h = -\dot{h}$ (squeeze velocity), and $w_0 = 0$ (the lower plate is impermeable).

Substituting u in equation (18) yields

$$\frac{d}{dx}\left[-\frac{h^3}{12\eta(1+\tau)}\frac{dp}{dx}+\frac{Uh}{2}\right]-\dot{h}=0. \tag{19}$$

The viscosity of the suspension is given by the Einstein formula [1]

$$\eta=\eta_0\left(1+\frac{5}{2}\phi\right). \tag{20}$$

From equations (19) and (20) we find that

$$\frac{d}{dx}\left[-\frac{h^3}{12\eta_0(1+\frac{5}{2}\phi)(1+\tau)}\frac{dp}{dx}+\frac{Uh}{2}\right]-\dot{h}=0. \tag{21}$$

Introducing the dimensionless parameters

$$\bar{x}=\frac{x}{l},\bar{h}=\frac{h}{h_1},\bar{p}=\frac{h_1^2 p}{U\eta_0 l},D=\frac{l\dot{h}}{Uh_1}, \tag{22}$$

then the equation (21) reduces to

$$\frac{d}{d\bar{x}}\left(\frac{-\bar{h}^3}{E}\frac{d\bar{p}}{d\bar{x}}+\frac{\bar{h}}{2}\right)-D=0, \tag{23}$$

where

$$E=12\left(1+\frac{5}{2}\phi\right)(1+\tau). \tag{24}$$

The film thickness in non dimensional form is taken as

$$\bar{h}=\frac{a}{1+\bar{x}\log a}. \tag{25}$$

Solving equation (23) under the boundary conditions

$$\bar{p}(1)=\bar{p}(0)=0, \tag{26}$$

the dimensionless pressure $\bar{p}$ can be obtained as

$$\bar{p}=-\frac{DE\left(\frac{1}{5}\bar{x}^5\log^3(a)+\frac{3}{4}\bar{x}^4\log^2(a)+\bar{x}^3\log(a)+\frac{\bar{x}^2}{2}\right)}{a^3}-\frac{1}{60a^3\log(a)(\log(a)+1)^4}\Big(E(-12D\log^4(a)-45D\log^3(a)-60D\log^2(a)-30D\log(a)+10a+10a\log^3(a)+30a\log^2(a)+30a\log(a))(\bar{x}\log(a)+1)^4\Big)+\frac{E(\bar{x}\log(a)+1)^3}{6a^2\log(a)} \tag{27}$$

The dimensionless load carrying capacity is

$$\bar{W}=\int_0^1\bar{p}\,d\bar{x}. \tag{28}$$

4 Results and Discussions

For numerical calculations $U=6.28\ ms^{-1}, l=0.02\ m$ are used in the computation. The calculated values of $\bar{W}$ for various values of ξ and ϕ when $\dot{h}=0$ are shown in figures 2a, 2b and 3, when $\dot{h}\neq 0$ are shown in figures 4 and 5. It is observed in figure 2a and 2b that when there is no squeeze velocity the load capacity increases for curvature up to $a=1.75$ and then decreases when $a>2$ for fixed value of Langevin's parameter ξ and varying volume concentration ϕ. Where as in figure 3 when ϕ is fixed and ξ is varying the load capacity increases with increasing curvature in the absence of squeeze velocity. In figure 4 we observe that load capacity will increases when volume concentration increases for decreasing curvatures with fixed $\xi = 1.5,\ \dot{h} = 0.02$. In figure 5 it is shown that load capacity will increases when langevin's parameter increases for different curvatures when $\phi = 0.075,\ \ \dot{h} = 0.02$.

5 Graphs

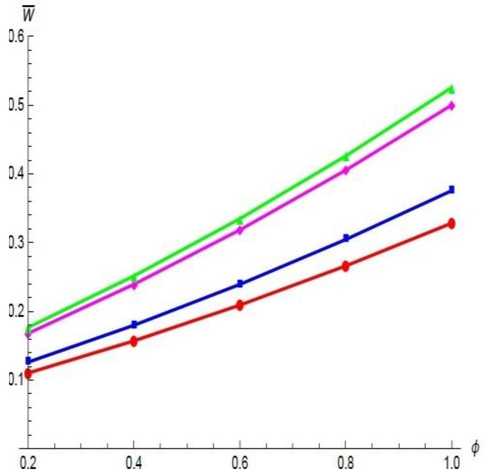

fig 2a. $\overline{W}$ versus ϕ when $\xi = 1.5$ and $\dot{h} = 0$

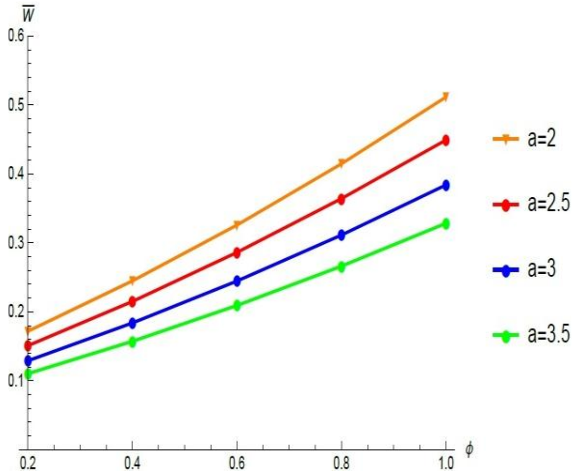

fig 2b. $\overline{W}$ versus ϕ when $\xi = 1.5,\ \dot{h} = 0$

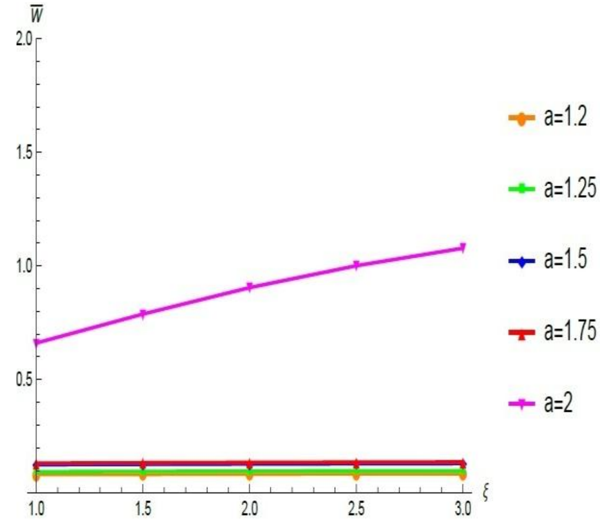

fig 3. $\overline{W}$ versus ξ when $\phi = 0.075$ and $\dot{h} = 0$

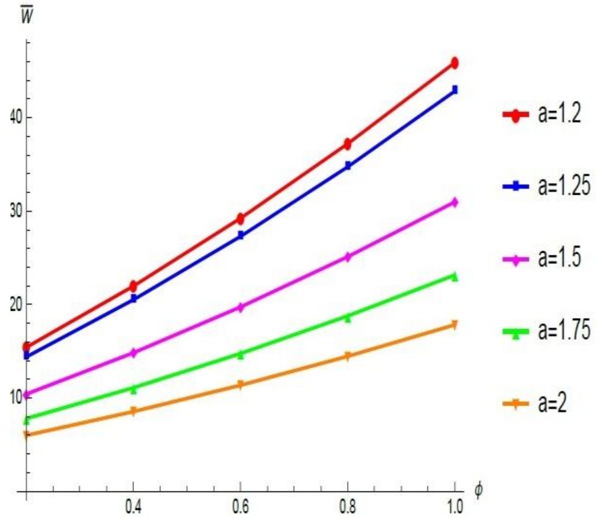

fig 4. $\overline{W}$ versus ϕ when $\xi = 1.5,\ \dot{h} \neq 0$

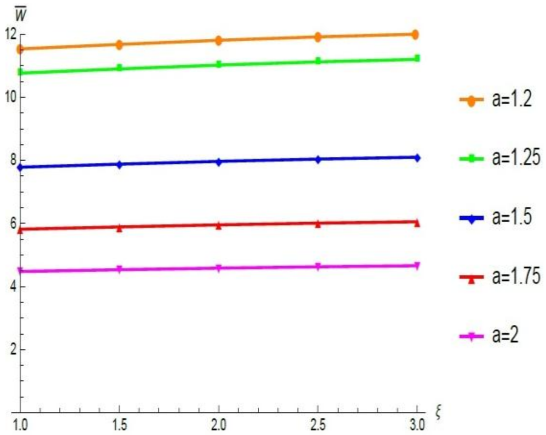

fig 5. $\overline{W}$ versus ξ when $\phi = 0.075,\ \ \dot{h} \neq 0$

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