Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 7, July 2021: 2154 – 2162

Mixed influence of Elastic deformation and variation in Viscosity on the Ferrofluid based porous rough short bearing

Dr. Mukesh E. Shimpi [a*], Dr. Jimit R. Patel [b], Dr. G. M. Deheri [c]

[a*] Department of Mathematics, BVM Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India-388120. Email: meshimpi@bvmengineering.ac.in
[b] Department of Mathematical Sciences, P. D. Patel Institute of Applied Sciences, Charotar University of Science and Technology (CHARUSAT), Changa, Anand, Gujarat, India-388 421. Email: patel.jimitphdmarch2013@gmail.com
[c] Department of Mathematical Sciences, P. D. Patel Institute of Applied Sciences, Charotar University of Science and Technology (CHARUSAT), Changa, Anand, Gujarat, India-388 421. Email: patel.jimitphdmarch2013@gmail.com

Abstract

The elastic deformation effect has been investigated in a porous rough short bearing lubricated by a Ferrofluid considering variation in viscosity. Tipei's pressure temperature expression is adopted to evaluate the impact of viscosity variation while the N-R's model has been assumed for the magnetic fluid flow. The modified Reynolds type expression for the distribution of pressure has been derived as a function of elastic deformation, viscosity variation, porosity and aspect ratio parameters. Then the load's calculation has been done. The graphical representations of Load Carrying Capacity (LCC) have been analyzed here with respect to various bearing parameters. This study suggests that the LCC can be raised by aggregating magnetization, viscosity variation and aspect ratio parameters while the decrease takes place when elastic deformation and porosity parameters are increased..

Keywords: Load Carrying Capacity; Elastic Deformation; Viscosity Variation; Magnetic fluid; Neuringer and Rosensweig's fluid flow model

1. Introduction

For the last many years, the slider bearings have been in used in Industry. The evidences are available in the literature ((1),(2),(3),(4)).The evolution of a converging lubricant wedge is the hydrodynamic slider bearing phenomenon that can be designed to provide this converging wedge in a variety of ways, such as plane, convex, concave, and stepped ones. Ferrofluid forms suspension of solid Ferro particles of sub domain size in a melted carrier, which remains liquid in a magnetic field and amends after field removal and recovery of their characteristics. For the last three decades, Ferrofluid lubrication in hydrodynamic bearings has been used in Loudspeakers and Sealing. It has many exciting properties, like, using an external magnetic field, it can be cramped to a desired spot. This property has been deployed in space craft vehicles. Most of the investigations during last decades discussed with constant velocity, however, in reality this is not always true. Of course, a few investigations deal with viscosity variation in the presence of conventional lubricants. ((1), (3), (4), (5)). It is well known that pumping power enhances as the viscosity increases, in fact, the viscosity variation effect gets a prominent place for decision of thermo fluid behaviour. A little ((6), (7), (8)) is known for the viscosity effect in the presence of a Ferrofluid governed by N-R Model. (9) analysed the impact of deformation and magnetic fluid on rough short bearing. It was concluded that up to a certain degree, the adverse consequences of the standard deviation could be neutralized when the deformation was relatively lower and by the joint positive impact of other parameters. For this point of view, it was thought to find out the elastic deformation and viscosity variation effect on the Ferrofluid lubrication of a rough porous short bearing.

2.1. Analysis

In the following Figure 1, the slider bearing surfaces of short bearing travels with uniform velocity u in x-direction. L and B are length and breadth in z direction with $B << L$. $\partial p / \partial x$ is neglected as per the discussion of (11).

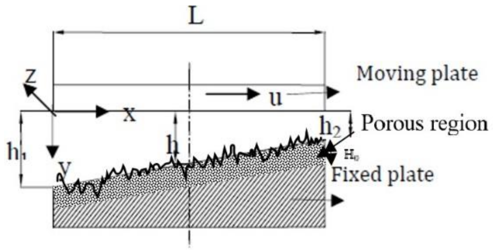

Figure 1. Short Bearing Configuration

According to (1), ferro field remains oblique to the starter. As per the discussions of (10), (3) the magnitude of the magnetic field is deemed to be

$$M^2 = kB^2 \left\{ \left(\frac{1}{2} + \frac{z}{B} \right) \sin\left(\frac{1}{2} - \frac{z}{B} \right) + \left(\frac{1}{2} - \frac{z}{B} \right) \sin\left(\frac{1}{2} + \frac{z}{B} \right) \right\}$$

(1)

"where k is a appropriately selected dimensionless constant" (3).

The usual conjuncture of hydrodynamic lubrication are take into account the laminar flow, the film thickness is presumed to be according to the model of (11) as

$$h(x) = \overline{h}(x) + h_s + \delta ,$$

"where $\overline{h}$ is the mean film thickness, δ being local deformation of the porous facing and h_s, the part due to surface roughness measured from the mean level $h + \delta$, is hypothetical to be stochastic in nature and governed by the probability density function discussed in (10).

A model was routed for the simple steady flow of Ferrofluid by (11) with a slowly changing external magnetic field and suggested following equation

$$-\nabla\left(p - \frac{\mu_0 \overline{\mu}}{2} M^2 \right) + \eta \nabla^2 \overline{q} = \rho\left(\overline{q} \nabla \right) \overline{q}$$

"where $\rho, q, \mu_0, \overline{\mu}, \eta$ and p denote the density of fluid, the fluid velocity, magnetic field's susceptibility, free space permeability, viscosity of fluid and the film pressure respectively."

Under hydro-magnetic lubrication theory, averaging and following magnetic fluid properties in a stochastic way ((10), (2)), the modified generalized Reynolds equation is calculated as

$$\frac{d^2}{dz^2}\left(p - \frac{\mu_0 \overline{\mu}}{2} M^2 \right) = \frac{6\mu u}{g(h)} \frac{d}{dx}\left(h + p_a p \delta \right) \quad (2)$$

where,

$$g(h)=(h+p_a p\delta)^3+3(h+p_a p\delta)^2\alpha+3(h+p_a p\delta)(\sigma^2+\alpha^2)+3\sigma^2\alpha+\alpha^3+\varepsilon+12\phi H_0$$

In view of the literature, lubricant's viscosity may change through the film and may be vary due to the reactions of surfactant and additives. As per suggestions of (11), it has been theoretically documented as the maximum temperature take place in the least film thickness zones. Here we consider the viscosity-temperature relation given there in as,

$$\mu=\mu_1\left[\frac{h}{h_2}\right]^{\xi} \qquad (3)$$

when the viscosity μ_1 is known at $h=h_2$, where $0<\xi<1$, the thermal factor, acts according to the behaviour of the lubrication ((6), (7), (8)).

The concerned Reynolds physical conditions at boundary associated with the system, are

$$p\left(\pm\frac{B}{2}\right)=0 \text{ and } \frac{dp}{dz}(0)=0 \qquad (4)$$

Solving equation (2) under boundary conditions (4), we can find the expression for dimensional pressure distribution with viscosity-temperature relation,

$$p=\frac{\mu_0\overline{\mu}}{2}M^2-\frac{3\mu_1 um}{g(h)L}h_2\left(1+m\left(1-\frac{x}{L}\right)\right)^{\xi}\left(z^2-\frac{B^2}{4}\right) \qquad (5)$$

The following non-dimensional quantities are introduce

$$m=\frac{h_1-h_2}{h_2}, Z=\frac{z}{B}, P=\frac{h_2^3}{\mu_1 uB^2}p, \mu^*=\frac{h_2^3 k\mu_0\overline{\mu}}{\mu_1 u}$$

$$X=\frac{x}{L}, \overline{L}=\frac{L}{h_2}, \overline{B}=\frac{B}{h_2}, \overline{\alpha}=\frac{\alpha}{h}, \overline{\sigma}=\frac{\sigma}{h}, \overline{\varepsilon}=\frac{\varepsilon}{h^3}, \overline{p}=p_a p', \overline{\delta}=\frac{\delta}{h}, \psi=\frac{\phi H_0}{h^3}, \overline{A}=1+m(1-X)$$

$$G=(1+\overline{p}\overline{\delta})^3+3(1+\overline{p}\overline{\delta})^2\overline{\alpha}+3(1+\overline{p}\overline{\delta})(\overline{\sigma}^2+\overline{\alpha}^2)+3\overline{\sigma}^2\overline{\alpha}+\overline{\alpha}^3+\overline{\varepsilon}+12\psi$$

With the help of above non-dimensional quantities, one can transform equation (5) turns into,

$$P=\frac{\mu^*}{2}\left[\left(\frac{1}{2}+Z\right)\sin\left(\frac{1}{2}-Z\right)+\left(\frac{1}{2}-Z\right)\sin\left(\frac{1}{2}+Z\right)\right]+\frac{3m}{\overline{L}\overline{G}}\left(\frac{1}{4}-Z^2\right)\left(\overline{A}\right)^{\xi-3} \qquad (6)$$

The non-dimensional LCC is found to be

$$W=\frac{h_2^3 w}{\mu_1 uB^4}=\mu^*\left[1-\sin(1)\right]-\frac{1}{2}\frac{1}{\overline{L}\overline{G}}\left[\frac{1-(1+m)^{\xi-2}}{\xi-2}\right] \qquad (7)$$

3.1. Results and Discussion

At the below, the analysis of the present problem, the followings are observed. The nondimensionalized pressure can be examined from Equation (6) while expression (7) determines the effect of non-dimensional LCC in the short bearing. It is detected from the equation (7) that the LCC augments due to the magnetic fluid lubrication in contrast with the usual fluid based bearing system and this is much more than the case of constant viscosity considered by a number of investigators ((1), (2), (3), (4)) eventually. This study reduces in the absence of elastic deformation, roughness and porous medium. Also, it moves to the study of after neglecting the viscosity variation.

The graphical representations of LCC with respect to various parameters of the short bearing can be exhibited in Fig. 2-11. The magnetization goes positively with respect to parameters of elastic deformations, viscosity variation, porosity and aspect ratio as evidenced in Fig. 2-5. Fig. 5 indicates that the above positive impact moves up further with a suitable choice of aspect ratio. It is established that the LCC improves due to magnetization which jells well with the theoretical consideration based on the linearity. Perhaps, it happens owing to the fact that the magnetization enhances the viscosity of the fluid.

Fig. 6-8 indicate that the increasing elastic deformation parameter causes decreased LCC.

The influence of viscosity variation parameter is exhibited in Fig. 9 and 10.

Fig. 11 displays the variation of LCC with respect to porosity and aspect ratio parameters. It is manifest that load carrying capacity increases with regards to m while it decreases concerning to ψ .

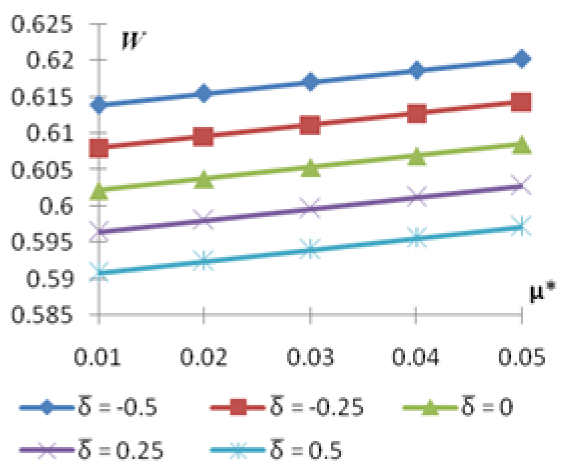

Figure 2. Profile of W with respect to μ^* and $\bar{\delta}$.

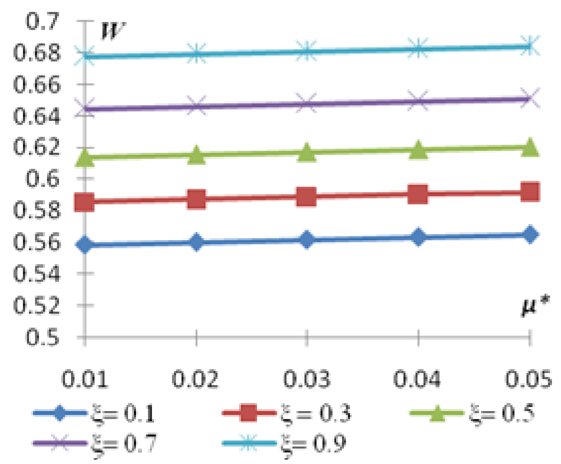

Figure 3. Profile of W with respect to μ^* and ξ .

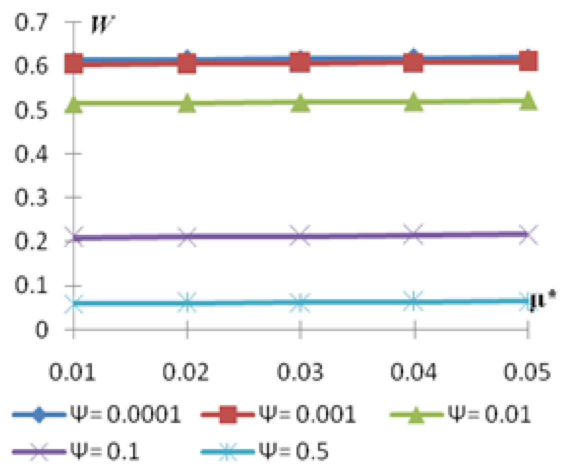

Figure 4. Profile of W with respect to μ^* and ψ.

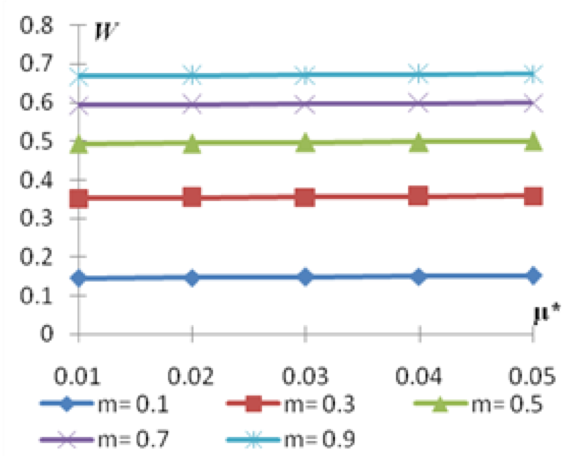

Figure 5. Profile of W with respect to μ^* and m.

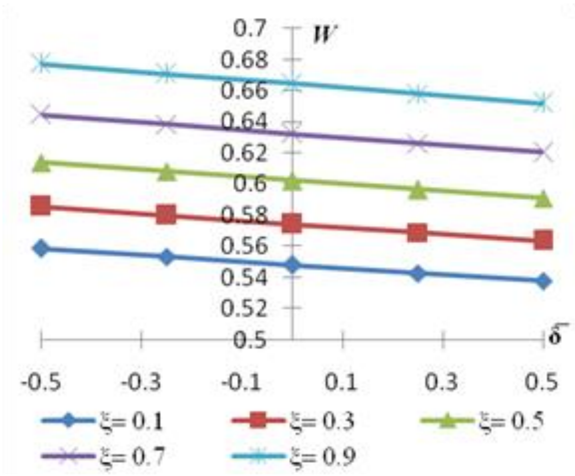

Figure 6. Profile of W with respect to $\bar{\delta}$ and ξ.

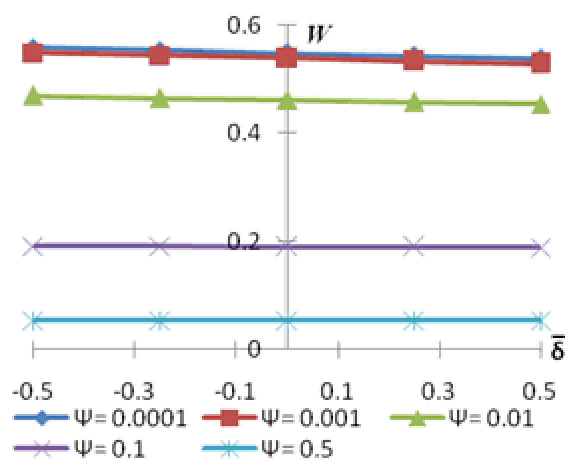

Figure 7. Profile of W with respect to $\bar{\delta}$ and ψ.

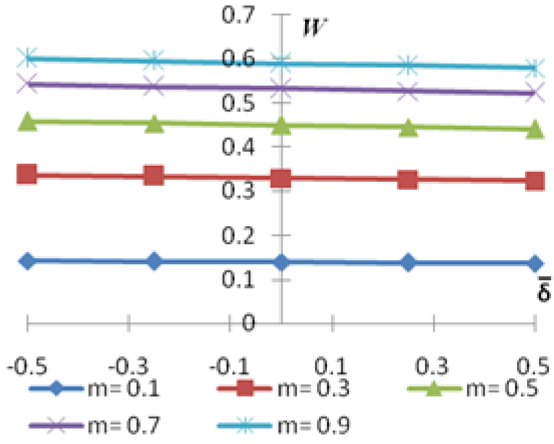

Figure 8. Profile of W with respect to $\bar{\delta}$ and m.

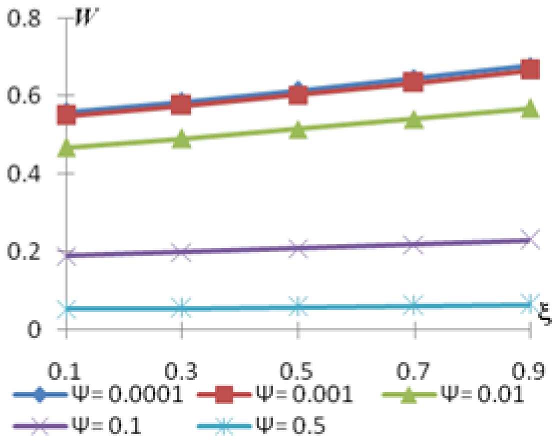

Figure 9. Profile of W with respect to ξ and ψ.

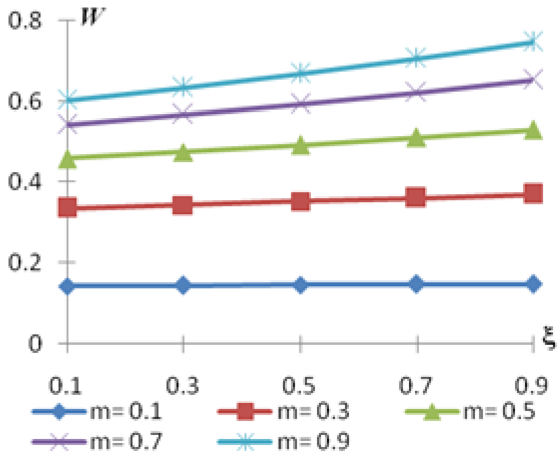

Figure 10. Profile of W with respect to ξ and m.

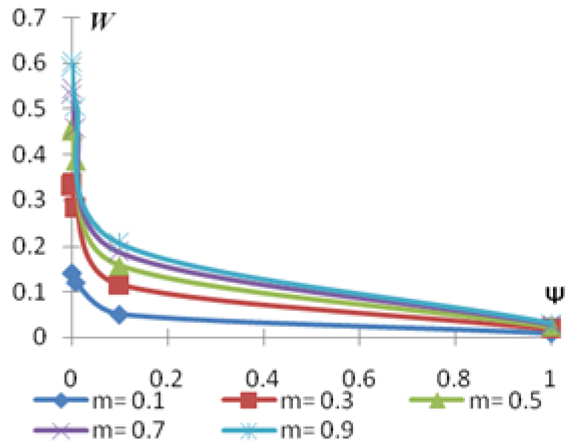

Figure 11. Profile of W with respect to ψ and m .

The graphical representations of the short bearing suggest the followings:

The positive effect of magnetic fluid lubricant can help to overcome the negative effect introduced by deformation and porosity in the case of negatively skewed roughness by selecting appropriately the viscosity variation and aspect ratio parameter. This effect is more apparent when variance (- ve) and lower values of deformation take place.

It is revealed that the LCC increases by increasing parameters of magnetization, viscosity variation and aspect ratio while decreases when elastic deformation and porosity parameters are increase. It is seen that deformation effect is more discernible to those of thermal consideration, while it reverse at the best moderate in the case of porosity.

It is noted that the viscosity variation effect fails to adequate to satisfy the effect of transverse roughness and deformation (even for smaller deformation).

4.1. Validation

Table 1. Profile of W with respect to ξ and m .

	□□	**0.1**	**0.3**	**0.5**	**0.7**	**0.9**
(12)	m= 0.1	0.147164	0.148522	0.149896	0.151288	0.152697
Present Study		0.142562	0.143874	0.145202	0.146546	0.147908
(11)		0.119611	0.120015	0.120419	0.120828	0.121243
(12)	m= 0.3	0.375272	0.384478	0.393984	0.403802	0.413945
Present Study		0.335692	0.343869	0.352326	0.361073	0.370123
(11)		0.173434	0.175903	0.178458	0.181103	0.183842
(12)	m= 0.5	0.552548	0.573284	0.595044	0.617886	0.641871
Present Study		0.458772	0.475369	0.492830	0.511210	0.530563
(11)		0.206349	0.21131	0.216553	0.222072	0.227892
(12)	m= 0.7	0.697571	0.731932	0.768493	0.807415	0.848868
Present Study		0.542145	0.56688	0.593280	0.621477	0.651613
(11)		0.227719	0.235053	0.242900	0.251302	0.260302
(12)	m= 0.9	0.818775	0.868044	0.921126	0.978352	1.040083
Present		0.601303	0.633372	0.668019	0.705489	0.746052

Study						
(11)		0.242300	0.251708	0.261910	0.272982	0.285008

Table 2. Profile of W with respect to ξ and σ.

	□□	0.1	0.3	0.5	0.7	0.9
(12)	$\bar{\sigma} = 0.01$	0.552548	0.573284	0.595044	0.617886	0.641871
Present Study		0.558787	0.585438	0.613975	0.644555	0.677349
(12)	$\bar{\sigma} = 0.05$	0.547986	0.568562	0.590155	0.612822	0.636624
Present Study		0.553040	0.579417	0.607660	0.637924	0.670381
(12)	$\bar{\sigma} = 0.09$	0.537638	0.557851	0.579065	0.601336	0.624723
Present Study		0.540082	0.565839	0.593418	0.622971	0.654664
(12)	$\bar{\sigma} = 0.14$	0.517601	0.537111	0.557589	0.579090	0.601672
Present Study		0.51529	0.539863	0.566173	0.594366	0.62461
(12)	$\bar{\sigma} = 0.19$	0.491401	0.509987	0.529499	0.549990	0.571514
Present Study		0.483464	0.506513	0.531192	0.557638	0.585999

Table 3. Profile of W with respect to ξ and $\bar{\alpha}$.

	□□	0.1	0.3	0.5	0.7	0.9
(12)	$\bar{\alpha} = -0.05$	0.469366	0.487101	0.505718	0.525267	0.545802
Present Study		0.463846	0.485956	0.509631	0.535000	0.562207
(12)	$\bar{\alpha} = -0.025$	0.434154	0.450611	0.467890	0.486037	0.505103
Present Study		0.424799	0.445042	0.466717	0.489943	0.514852
(12)	$\bar{\alpha} = 0$	0.402515	0.417820	0.433892	0.450774	0.468513
Present Study		0.390234	0.408823	0.428728	0.450057	0.472931
(12)	$\bar{\alpha} = 0.025$	0.374018	0.388282	0.403263	0.419001	0.435541
Present Study		0.359496	0.376615	0.394945	0.414588	0.435653
(12)	$\bar{\alpha} = 0.05$	0.348289	0.361610	0.375603	0.390305	0.405758
Present Study		0.332047	0.347853	0.364778	0.382914	0.402363

A comparison of the present study with the above mentioned ones indicates that the thermal effect may not have much of influence in the performance even if there is a cognizable amount of deformation. Probably, this could be due to the positive aspect of magnetic fluid lubrication (Table 1).

A contrast in table 2 indicates that even though the deformation is raised, the positive effect of the standard deviation is obvious. Lastly, the fact that the impact of variance is relatively less compared to the study of [11], which is informed by table 3.

The outcome of these investigations in comparison with earlier once goes on to tell that the combined influence of magnetism and viscosity discrepancy may be nearly sufficient to content the adverse effect of deformation.

4.1. Conclusion

This study may be helpful to the industry by picking up parameters suitably to design this type of short bearing. This investigation makes it clear that the performance of the bearing system enhances due to N-R's fluid flow model for the magnetic fluid. The development of deformation in bearing tends to suggest strongly that the roughness must be addressed carefully even if magnetization parameter and viscosity variation parameter are suitably chosen. Moreover, the bearing can support some lifting force for all range of deformation, viscosity, porosity and aspect ratio. Although, lots of work has been done in the field of roughness, unfortunately, bearing deformation in general has gained a little attention. Therefore, this direction of investigation is to be address theoretically as well as experimentally.

Acknowledgement: The novelists recognize the valuable remarks and recommendations of the referees, which have contributed to the development of the manuscript's presentation and organization.

References

[1] Agrawal, V. K. (1986). Magnetic Fluid based porous inclined slider bearing, Wear, 107(2), 133-139.

[2] Deheri, G. M., Andharia, P. I., & Patel, R. M. (2005). Transversely rough slider bearings with squeeze film formed by a magnetic fluid, Int. J. of Applied Mechanics and Engineering, 10(1), 53-76.

[3] Patel, J. R., & Deheri, G. M. (2013). A comparison of porous structures on the performance of a magnetic fluid based rough short bearing, Trib. in Ind., 35(3), 177-189.

[4] Patel, J. R., & Deheri, G. M. (2015). A comparison of different porous structures on the performance of a magnetic fluid based double porous layered rough slider bearing, Int. J. of Mate. Lifetime, 1(1), 29-39.

[5] Patel, N. S., Vakharia, D. P., Deheri, G. M., & Patel, H. C. (2017). Experimental performance analysis of ferrofluid based hydrodynamic journal bearing with different combination of materials, Wear, 376-377, 1877-1884.

[6] Siddangouda, A., Biradar, T. V., & Naduvinamani, N. B. (2013). Combined effects of surface roughness and viscosity variation due to additives on long journal bearing, Tribology - Materials, Surfaces & Interfaces, 7(1), 21-35.

[7] Patel, J. R., Deheri, G. M., & Patel, P. A. (2018). Ferrofluid lubrication of Journal bearing with thermal effects, Mathematics Today, 34A, 92-99.

[8] Prakash, J. & Peeken, H. (1985). The combined effect of surface roughness and elastic deformation in the hydrodynamic slider bearing problem, Tribol. Trans., 28(1), 69–74.

[9] Basu, S. K., Sengupta, S. N., & Ahuja, B. B. (2005). Fundamentals of Tribology, Prentice-Hall of India Private Limited, New Delhi.

[10] Christensen, H. & Tonder, K. C. (1970). The hydrodynamic lubrication of rough bearing surfaces of finite width, ASME-ASLE Lubrication Conference, Paper no.70.

[11] Patel, JR, & Deheri, G. (2019). Viscosity variation effect on the magnetic fluid lubrication of a short bearing, Journal of the Serbian Society for Computational Mechanics, 13(2), 56-66.

[12] Munshi, M. M., Patel, A. R., & Deheri, G. M. (2019). Lubrication of Rough Short Bearing on Shliomis Model by Ferrofluid Considering Viscosity Variation Effect, International Journal of Mathematical, Engineering and Management Sciences, 4(4), 982–997.