Influence of Nano-Fluid Lubrication On Single Porous-Layered Journal Bearing: A Hypothetical Approach

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Influence of Nano-fluid lubrication on Single Porous-Layered Journal Bearing: A Hypothetical Approach

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Abstract:

In this article a mathematical model of single layered nano-fluid lubricated PJB (porous journal bearing) has been formulated. The nano-lubricant's impact on the efficiency of said journal bearing has been studied using modified Darcy's law and boundary conditions. The different nanoparticles often used as an additive in industrial lubricating oils improve their viscosity significantly. The brief description of dimensionless performance characteristics of the investigated bearing was obtained by the use of the nano-lubricant's modified Krieger-Dougherty viscosity model. The observations revealed that the output characteristics are substantially improved by using nano-lubricant. The present study was validated by comparing the findings of recently published data with micropolar fluid and was found to be completely compatible since data with nano-lubricant are still unavailable.

Keywords: *Nano-lubricant; Porous layer; Journal bearing; Modified Krieger-Dougherty Equation.*

1. Introduction:

Over the last two decades, tribologists have used nanoparticles as lubricant additives for better performance between contact surfaces of the bearing. The addition of various nanoparticles enhances the performance ability of those machine parts by reducing the friction and wear rate. The Newtonian and non-Newtonian lubrication models are theoretically and experimentally analysed by many researchers in case of different types of porous bearings. The application of nano-Newtonian lubricants is rapidly increasing in various field of engineering due to their superior lubricating property.

The depreciation of frictional energy loss will result in a weighty reduction in energy consumption and an enhancement in the efficiency of the machine. This phenomenon will occur when a nano-lubricant is used in such machinery [1]. Recently, the researchers of the tribology field, have used nanoparticles as an additive of conventional lubricant for better performance between the rubbing surfaces of the bearing. Xiaodong *et al.* [2], Ginzburg *et al.* [3], and Hu *et al.* [4] perceived that nanoparticles present in the nano-lubricant develop a protective coating (film) over the surfaces under friction. Then, it prevents the surface to surface contact as well as the frictional loss of those mating parts. Liu *et al.* [5] and Tao *et al.* [6] noticed that the deposition of nanoparticles (as an additive of lube oil) on the friction surfaces compensated by the material loss. The abrasive action of nanoparticles also reduces the roughness of friction surfaces. Nair *et al.* [7] theoretically studied the static and dynamic characteristics of a nano-fluid lubricated hydrodynamic journal bearing. The modified Reynolds equation was developed for finding pressure distribution in the clearance space of bearing and also end leakage flow, stiffness coefficient, load capacity, threshold speed etc. Shenoy *et al.* [8] also studied that the performance of externally adjustable fluid film bearing is significantly affected by the use of nanoparticle additives on lubricant. The research work carried out in Ref. [7-8] reported that the stability and load capacity of journal bearings are extensively improved by the use of a nano-lubricant. Chand *et al.* [9] investigated the impact of couple-stress nano-fluid in the thermal instability of a horizontal porous medium with the help of Darcy's model of flow. The porosity and couple stress parameter have the ability to stabilise the medium. Binu *et al.* [10] suggested that the addition TiO_2 nanoparticle in base lubricant enhances the load-bearing capacity of journal bearing. The modified viscosity model of Krieger-Dougherty is applied for theoretical modelling of such problem and also solved by using a numerical technique. They also discerned that the performance characteristics of the journal bearing are extensively improved by using the nanoparticles as lubricant additive.

The tribologists around the world are interested in the theoretical and experimental research of various types of advanced and modified journal bearings. The porous journal bearing is one of the subjects of research interest among those tribologists. Recently, Bhattacharjee *et al*. [11-12] investigated the operating characteristics of both single and double-layered PJB under the lubrication of micropolar fluid. The micropolar lubricant or fluid is a kind of non-Newtonian fluid which consisting of conventional lubricant and micro-particles (1 to 1000 μm in size) as additive. The load capacity, stiffness coefficient and mass flow rate are extensively improved by using micropolar lubricant in these two cases. Patel *et al*. [13] analysed infinitely long porous slider bearing lubricated with a thin film of ferrofluid at the nanoscale. The Reynolds equation and other non-linear differential equations solved by using Neuringer-Rosensweig's model.

The thin film of nanoscale lubrication showed an all-around improvement in the performance of the bearing. Singh *et al*. [14] showed a theoretical model of inclined porous slider bearing incorporating magnetic fluid. The load parameter of said bearing enhanced with the increase in the magnetic parameter and reduced with the decrease in permeability. So, the porosity of the porous layer needs to be optimised. Rao *et al*. [15] investigated a three-layered journal bearing lubricated with couple stress fluid in addition with nanoparticles into the lubricant. The volume fraction of nanoparticles is directly proportional with the load capacity and inversely proportional with the frictional coefficient. Bhat *et al*. [16] evaluated the expression of pressure, pressure centre, frictional force, load capacity, and coefficient of friction in the case of magnetic fluid lubricated porous composite slider bearing. They also stated that the capacity of said bearing to carry the load increases with the application of magnetic fluid and also shifted pressure centre towards the inlet for reducing the friction. Jamalabadi [17] numerically analysed a nano-fluid lubricated plain journal bearing with long and short bearing approximation. The addition of nanoparticles (like CuO, TiO_2, Ag and Cu) on to the base lubricant, results in an increase in fluid stiffness, damping ratio and mass coefficient.

Patel *et al*. [18] investigated the performance of parabolic porous slider bearing under hydro-magnetic lubrication. The magnetisation effect of the said lubricant showed a significant improvement in the steady-state characteristics of this bearing. Babu *et al*. [19] evaluated a non-dimensional modified Reynolds equation in case of plain journal bearing under nano-lubricant, which contains aluminium and zinc oxide nanoparticles. Due to that the viscosity index of nano-lubricant is increased. That's why the journal bearing performed more efficiently as compared with the conventional lubricants. A double-layered PJB lubricated with gas is analysed by Bhattacharjee *et* al. [20-21]. They observed that the performance and efficiency of the double-layered PJB are significantly improved as compared to the single-layered porous bearing.

However, the theoretical analysis of the beneficial effect of nano-lubricant into a porous journal bearing has so far not been reported. The researchers of tribology field didn't consider the influence of size, aggregation properties of nanoparticle and the variation of viscosity of lubricant with the addition of nanoparticle into it. The gaps found in literature and lack of research work on this topic, motivated the authors to perform a theoretical investigation of single porous-layered journal bearing incorporated with nano-lubricant. Therefore, the purpose of this work is to acquire a thorough knowledge of the effects of nano lubricants on porous journal bearing.

2. Mathematical Evaluation:

A single porous-layered journal bearing be made up of a permeable bush (contains fine particles of size 2.5 μm) is fitted with an impermeable bearing housing and a journal, as indicated in Figure 1. The mathematical analysis of such bearing system requires some assumptions [1-20] of the porous layer and hydrodynamic nano-fluid film. These are given below.

1. The nano-fluid flow through the porous layer follows the modified Darcy's law.
2. The flow of nano-fluid is laminar and also viscous.
3. An isotropic and uniform porous layer is used.
4. The nano-lubricant is non-Newtonian and incompressible.

The viscosity of a lubricating fluid directly makes a substantial impact on the performance of PJB. The viscosity model of nano-lubricant was first developed by Einstein in 1956. After that, this model was modified several times by the different researchers [1-10]. Finally, in 2007, the modified Krieger-Dougherty viscosity model of nano-fluid was expressed as follows:

$$\vartheta_{nl} = \left(1 - \frac{\delta_a}{\delta_m}\right)^{-2.5\delta_m} \tag{1}$$

Here,

$$\delta_a = \delta\left(\frac{a_a}{a}\right)^{3-d} \tag{2}$$

Here, δ, δ_a and δ_m are the volume fraction of nanoparticle, the effective volume fraction and the maximum particle packing fraction, respectively. The fractal index is indicated as *d*.

The viscosity of nano-fluid incorporated with modified Darcy's law furnishes the equation of flow nano-lube oil through the porous layer, as expressed below:

$$q_{nl} = -\frac{k}{(\vartheta_{bl} + \vartheta_{nl})}\Delta p \tag{3}$$

Here, $k, q_{nl}, \vartheta_{bl}$, ϑ_{nl}, and Δp represented as the permeability of the porous medium, modified Darcy's flow velocity, the viscosity of base lubricant and nano-lubricant and the change in fluid pressure respectively.

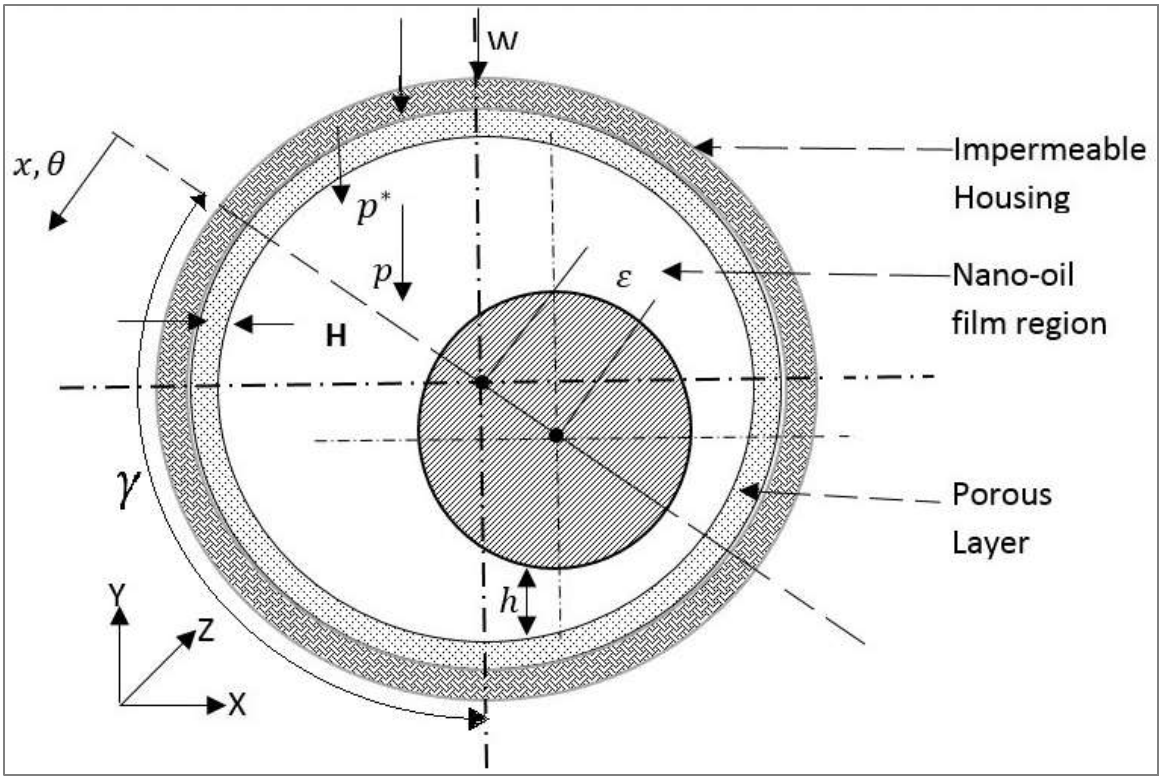

Figure 1: The geometry of single-layered PJB.

The nano-fluid flow equation in the porous layer can be expressed by virtue of above-mentioned assumptions, modified law of Darcy (Eq. 3) and law of conservation of mass. The expression is given below:

$$k_x \frac{\partial^2 p^*}{\partial x^2} + k_y \frac{\partial^2 p^*}{\partial y^2} + k_z \frac{\partial^2 p^*}{\partial z^2} = 0 \tag{4}$$

Here, k_x, k_y and k_z are the components of permeability coefficient (k) of the porous layer in all three direction. The pressure of nano-fluid inside the porous layer is denoted as p^*.

The viscosity of nano-lubricant (Eq. 1), the modified Darcy's law (Eq. 3) and lubricant flow equation (Eq. 4) through porous layer are used to develop the modified Reynolds equation of single porous–layered journal bearing [11]. The non-dimensional form of the same in the nano-fluid film zone of PJB is as given below.

$$\frac{\partial}{\partial \theta}\left[\left\{\frac{6k_x\bar{h}^3}{(\vartheta_{bl}+\vartheta_{nl})}\right\}\frac{\partial \bar{p}}{\partial \theta}\right] + \left({}^{D}/_{L}\right)^2 \frac{\partial}{\partial \bar{z}}\left[\left\{\frac{6k_z\bar{h}^3}{(\vartheta_{bl}+\vartheta_{nl})}\right\}\frac{\partial \bar{p}}{\partial \bar{z}}\right] = 18\alpha\xi\bar{\mu}\frac{\partial}{\partial \theta}\left(\bar{p}.\bar{h}\right) + \beta\frac{\partial \overline{p^*}}{\partial \bar{y}} \tag{5}$$

Here,

$$\xi = \text{ Bearing Number} = \frac{9\vartheta_{nl}R^2}{\bar{k}\bar{H}\bar{h}^3\left(\bar{h}^3 + 6\bar{H}\right)} \tag{6}$$

$$\alpha = \text{Permeability Parameter} = \frac{\bar{k}\bar{H}}{C^3} \tag{7}$$

$$\bar{\mu} = \text{Non} - \text{dimensional relative viscosity} = \frac{\vartheta_{nl}}{\vartheta_{bl}} \tag{8}$$

$$\beta = \text{Feeding parameter of bearing} = \frac{8R^2k_y}{HC^3} \tag{9}$$

Now, from Fig.1, the dimensionless expression of the nano-fluid film thickness is verbalized as follows:

$$\bar{h} = 1 + \varepsilon(\cos\theta + \cos\gamma) \tag{10}$$

The required substituting parameters to get the non-dimensional modified Reynolds equation are as follows:

$$\bar{h} = {}^{h}/_{c}\,;\ \bar{y} = {}^{y}/_{H}\,;\ \bar{z} = {}^{z}/_{L}\,;\ \theta = {}^{x}/_{R}\,;\ \bar{p} = \frac{pC^2}{\omega R^2\vartheta_{bl}} \tag{101}$$

The modified Reynolds equation (Eq. 5) needs to solve numerically with the help of some general boundary conditions, which are given below:

I. In the clearance space of bearing,

$$\begin{aligned} &\text{At } (\theta, 0),\ \bar{p} = 0 \\ &\text{At } (\theta, 1),\ \bar{p} = 0 \\ &\text{At } (\theta, \bar{z}),\ \bar{p} = 0 \\ &\text{If } \theta_2 \le \theta \le \theta_1 + 2\pi^c, \text{then } \frac{\partial\bar{p}(\theta_2,\bar{z})}{\partial\theta} = 0 \end{aligned} \tag{12a}$$

The positions where the film of nano-fluid breaks up and builds up are denoted as θ_2 and θ_1 respectively.

II. In the porous matrix,

$$\begin{aligned} &\text{At } (\theta, \bar{y}, 0),\ \overline{p^*} = 0 \\ &\text{At } (\theta, \bar{y}, 1),\ \overline{p^*} = 0 \end{aligned} \tag{12b}$$

III. In the impermeable housing,

$$\frac{\partial\overline{p^*}(\theta, -1, \bar{z})}{\partial\bar{y}} = 0 \tag{12c}$$

The porous matrix equation (Eq. 4) and the modified Reynolds equation (Eq. 5) need to solve numerically for obtaining the pressure of nano-oil inside the porous layer ($\overline{p^*}$) and the lubricant film pressure ($\bar{p}$) respectively. For solving the non-linear differential equations like Eq. 4 & 5, the above expressed boundary conditions such as Eq. 12a, 12b & 12c are very essential.

Now, the solution process of Eq. 4 & 5 are carried out with the help of fourth-order Runge-Kutta method with a time step, $\Delta t = \left\{\frac{5\pi}{180}\right\}^c$. A standard coding software is used to perform the all solution steps required to solve Eq. 4 & 5.

3. Bearing Performance Characteristics:

The fluid film pressure distribution in the clearance space can be acquired from the solution of Eq. 5. Now, this known pressure is being employed to derive the expression of different bearing performance characteristics such as load-carrying capacity, volume flow rate of nano-lubricant, stiffness of porous journal bearing.

The non-dimensional parameter of load-bearing capacity of the investigated bearing consists of two vector components. These two components can be evaluated by integrating the elementary load of fluid film pressure, which are expressed as follows:

(i) Dimensionless radial component of load capacity

$$\overline{W_r} = \frac{W_r \xi^2}{LD\vartheta_{nl} P_a} = \int_0^{2\pi} \int_{\bar{z}=0}^{\bar{z}=1} \bar{P} \cos\theta \ d\theta \ d\bar{z} \tag{13}$$

(ii) Dimensionless tangential component of load capacity

$$\overline{W_t} = \frac{W_t \xi^2}{LD\vartheta_{nl} P_a} = \int_0^{2\pi} \int_{\bar{z}=0}^{\bar{z}=1} \bar{P} \cos\theta \ d\theta \ d\bar{z} \tag{14}$$

Therefore, the resultant non-dimensional expression of load-capacity of a porous journal bearing is as follows:

$$\bar{W} = \frac{W \xi^2}{LD\vartheta_{nl} P_a} = \sqrt{(\overline{W_r})^2 + (\overline{W_\emptyset})^2} \tag{15}$$

Now, the expression dimensionless volume flow rate of nano-lubricant is as given below.

$$\bar{M} = \frac{\xi L \omega^2}{DC^3 P_s} (\vartheta_{nl} + \vartheta_{bl}) M = -\frac{1}{12} \int_0^{2\pi} \left\{\frac{\partial \bar{P}}{\partial \bar{z}}\right\}_{\bar{z}=1} \bar{h}^3 \ d\theta \tag{16}$$

The stiffness coefficients of the investigated bearing are expressed mathematically in the following manner.

$$K_{xx} = \left[8\varepsilon\beta \left(\frac{L\delta_a}{D}\right)^2 \frac{k_x}{k_y} \int_0^{\pi} \frac{\sin\theta \cos^2\theta}{h^4} d\theta\right] - \left[2\xi \left(\frac{L\delta_a}{D}\right)^2 \frac{k_x}{k_y} \int_0^{\pi} \frac{\sin\theta \cos\theta}{h^3} d\theta\right] \tag{17}$$

$$K_{yy} = \left[2\xi\beta\left(\frac{L\delta_a}{D}\right)^2 \frac{k_y}{k_x}\int_0^{\pi}\frac{\sin\theta\cos\theta}{h^3}d\theta\right] + \left[8\varepsilon\left(\frac{L\delta_a}{D}\right)^2 \frac{k_y}{k_x}\int_0^{\pi}\frac{\sin\theta\cos^2\theta}{h^4}d\theta\right] \quad (18)$$

The mathematical expression of load carrying capacity (Eq. 13 & 14), volume flow rate (Eq. 16) and stiffness coefficient (Eq. 17 & 18) contain definite integral parts. The solutions of the definite integral parts are not so easy with the conventional method. That's why Simpson's three by eight (3/8) rule is implemented to evaluate the equations comfortably. Standard programming software is used to create and run programming of Simpson's 3/8 rule for generating the design charts of different bearing performance against various bearing parameters. This programming is designed in such a manner that it is automatically terminated when the divergence between two successive values come under 0.0005 and the number of the interval is taken in the range of 32 to 64. The reason to choose such values is to generate precise and accurate results and also to reduce the computational time taken by the software.

4. Results & Discussion:

The graphical representations of the influence of nano-fluid properties to the performance of porous journal bearing are shown in Figure 2 to 10. The performance of the investigated journal bearing is significantly affected by the bearing number (ξ), effective volume fraction (δ_a) of nano-fluid and bearing feeding parameter (β). The various design parameters, such as R/C, H/R, k_x, k_z, are taken as constant for evaluating the different performance characteristics of porous journal bearing. In this section, the benefit of using nano-lubricant over micropolar lubricant has been discussed elaborately.

With the intention of proper validation of the present observations, the outcomes of the present analysis are assessed with the same as obtained by Binu *et al.* [10] and Bhattacharjee *et al.* [11]. The comparative graphs and tables proved that the current theoretical investigations are in good agreement.

Pressure ratio (P_s/P_a)	**Volume flow rate**			
H=	**4.00**	**4.50**	**5.00**	**4.00 Ref. [11]**
0.8	1.050	1.040	1.020	1.040
2.2	1.130	1.120	1.110	1.110
3.2	1.199	1.195	1.190	1.180
4.2	1.240	1.230	1.210	1.210
5.2	1.380	1.320	1.290	1.350
6.2	1.500	1.450	1.400	1.450
7.2	1.610	1.550	1.500	1.570
8.2	1.800	1.700	1.580	1.740
9.2	1.900	1.820	1.770	1.820
10.8	2.180	1.990	1.840	1.980

Table 1: Deviation of volume flow rate against pressure ratio for different porous bushing thickness and divergence with the hitherto published results of Ref. [11].

4.1 Volume Flow Rate:

The rate of volume flow of nano-lubricant within the investigated bearing changes with the variation of pressure ratio, bearing feeding parameter and effective volume fraction of nano-fluid. The volume flow rate is also getting effected by the change in the permeability coefficient of the porous layer because the permeability of porous layers and medium permits the nano-lube oil to flow through it. The flow of nano-lubricant inside the porous journal bearing carry the applied load to the bearing when necessary and restore to its original position with the removal of applied load from bearing. This phenomenon of the porous bearing increases its life span as compared with conventional bearings.

The validation of the observation of the volume flow rate of the present analysis is presented in Fig. 2. The outcomes obtained in the this work are judged with the results published previously in Ref. [11] and found that the rate of flow of nano-fluid through the porous layer is much improved in contrast with the same of micropolar fluid. The reason behind it is the improved viscosity of nano-fluid. The trend of Fig. 2 shows that the volume flow rate of nano-fluid increases with the decrease in porous layer thickness and the rise in pressure ratio because the size of the nano-particles present in the nano-lubricant is in the range of 1 to 100 nanometer (nm).

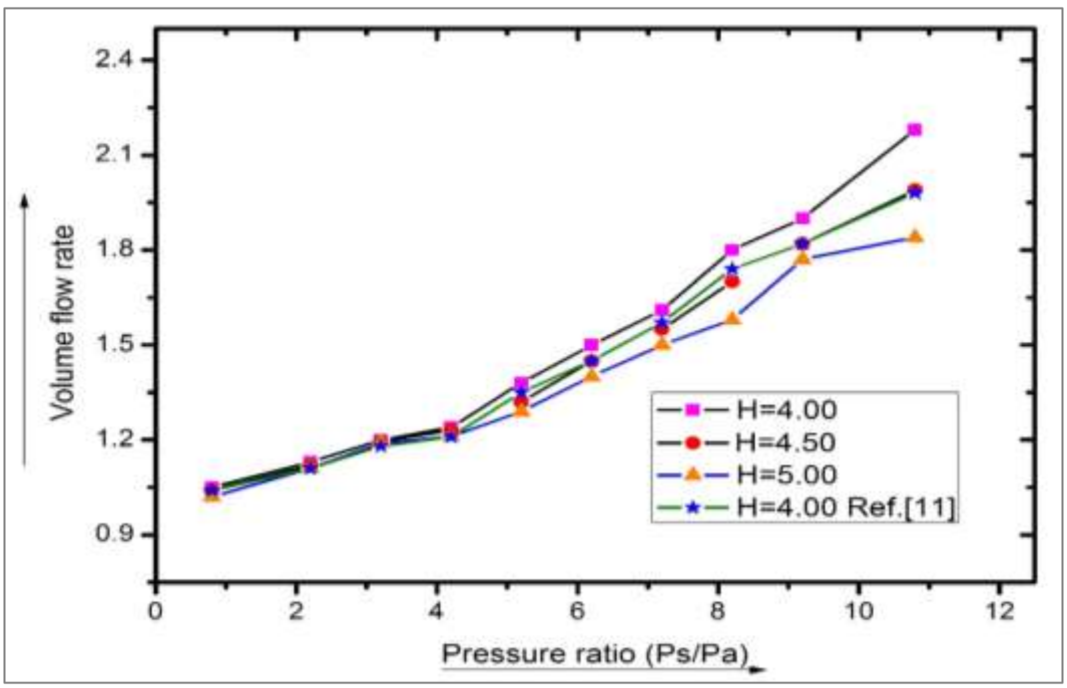

Figure 2: The variation of volume flow rate against pressure ratio for different porous bushing thickness.

The deviation of the volume flow rate of nano-fluid influenced by the bearing number concerning the different effective volume fraction of nano-fluid is illustrated in Fig. 3. The effective volume fraction is a significant parameter of nano-fluid viscosity as per the Eq. 1. The Fig. 4 depicts that the rate of volume flow is enhanced with the increase in bearing feeding parameter (β) and different bearing number (ξ). The bearing feeding parameter boosts the lube oil flow through the porous layer which reduces the bearing clearance area as well as film pressure.

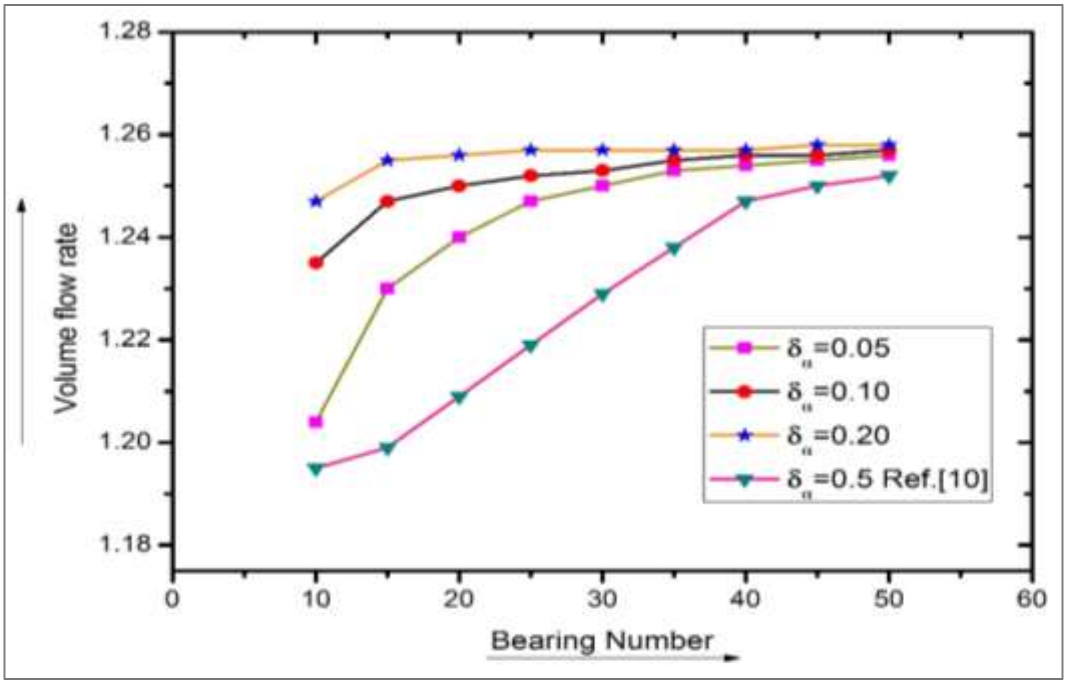

Figure 3: Influence of effective volume fraction (δ_a) on the rate of volume flow with the bearing number (ξ).

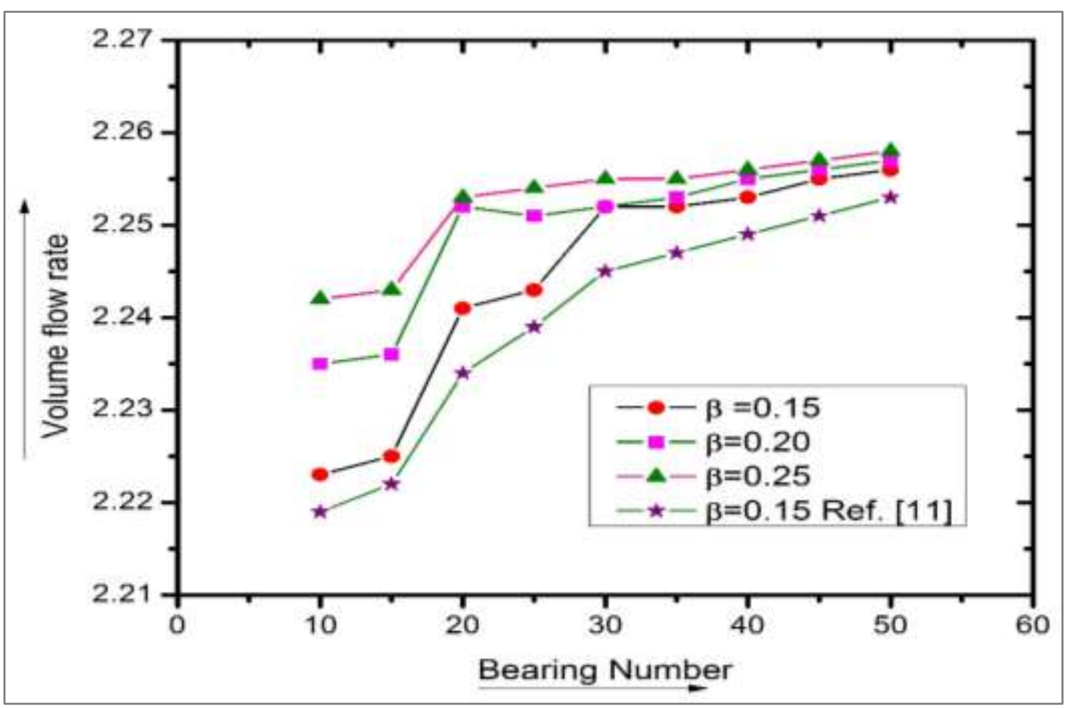

Figure 4: Variation of the rate of volume flow with bearing feeding parameter (β) and different bearing number (ξ).

4.2 Load Carrying Capacity:

The load-carrying capacity of bearing is a very significant parameter, which mainly defines the efficiency of any bearing. The consequence of porous bushing thickness (H) and the pressure ratio (P_s/P_a) into the capacity of the inspected bearing to carry the load are shown in Fig. 5. The trend of the graph (Fig. 5) shows that the load capacity is getting curtailed up to a particular limit with the boost in thickness of porous bushing (H) and the pressure ratio (P_s/P_a). The pressure inside the porous layer increases with the enhancement of porous layer thickness. The load capacity of PJB (the investigated bearing) tends to reduce because of the lack of flow of nano-lube oil through the porous layer when its thickness increases.

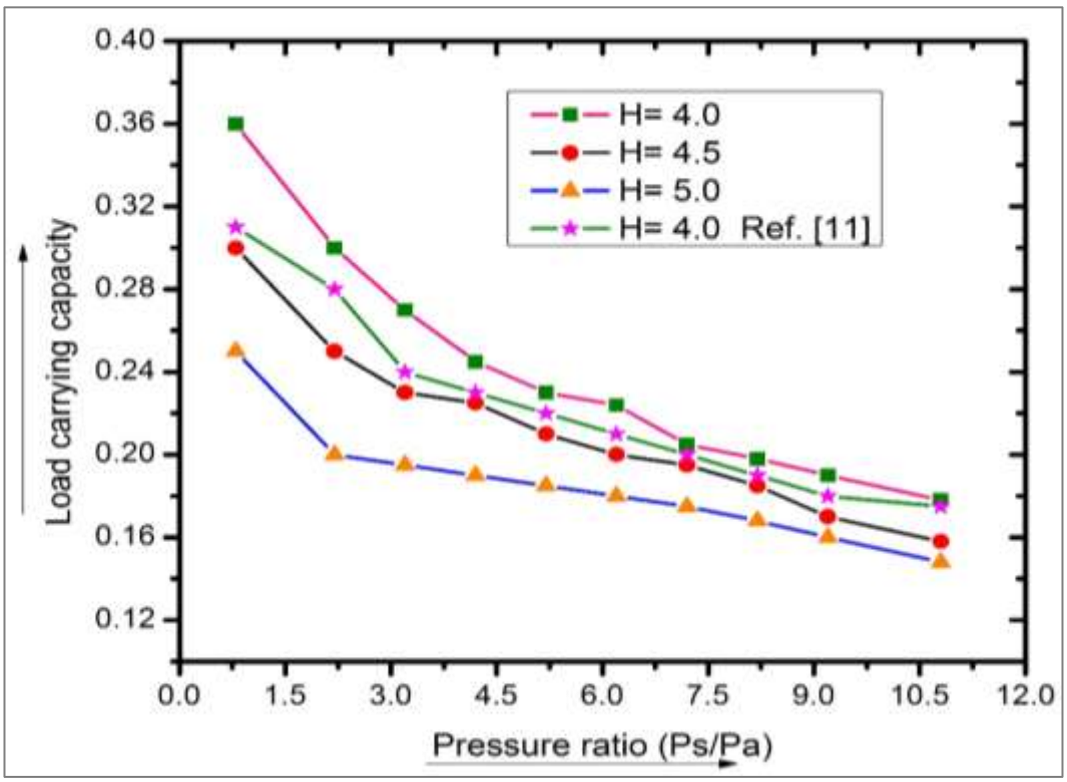

Figure 5: Variation of load carrying capacity against pressure ratio concerning different porous bushing thickness (H).

Figure 6 describes the enhancement of load capacity of porous journal bearing with bearing number for different quantities of effective volume fraction of nano-fluid. The viscosity of nano-fluid changes with effective volume fraction and the load capacity is also altered with the viscosity of the different lubricant. In such way, the effective volume fraction significantly put an impact on the load-bearing capacity of the investigated bearing. It is perceived from Fig. 7 that the load capacity of porous bearing is also influenced by the variation of bearing feeding parameter and bearing number. The bearing feeding parameter mainly be dependent on the thickness and permeability coefficient of the porous layer. It will decrease if the thickness of the porous layer increased. The results observed in Fig. 5 to Fig. 7 are compared with the published results of Ref. [10 & 11] which depicts that these results are in perfect covenant.

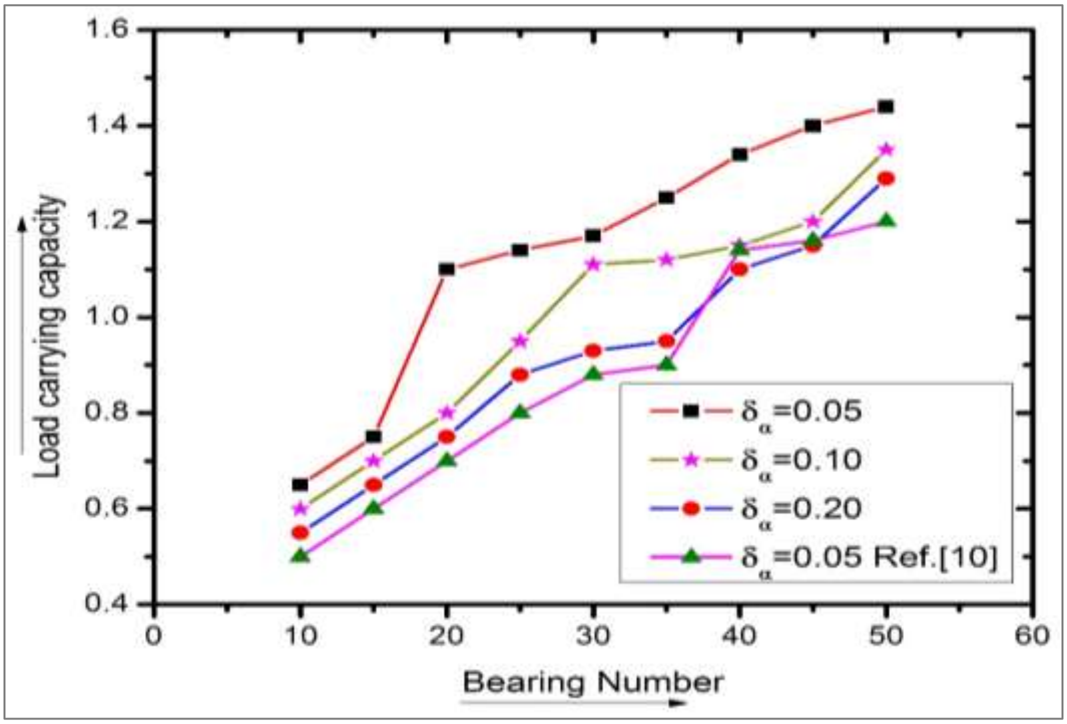

Figure 6: Influence of effective volume fraction (δ_a) on the load capacity of porous journal bearing with different bearing number (ξ).

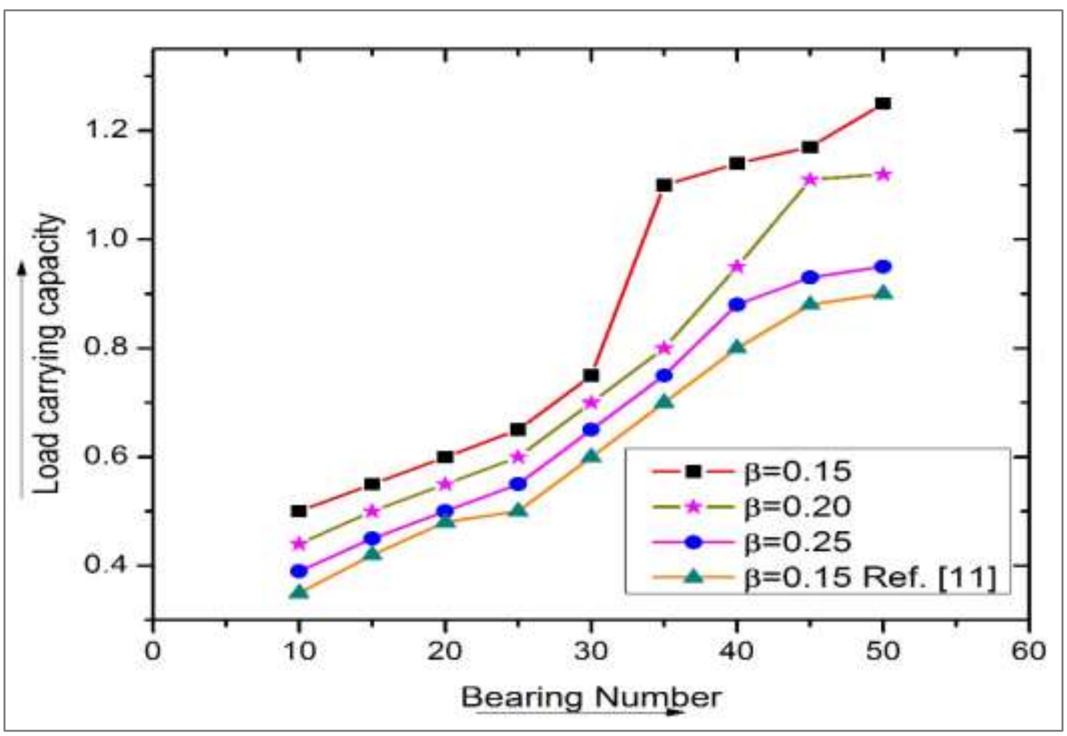

Figure 7: Deviation of load-carrying capacity with bearing feeding parameter (β) and different bearing number (ξ).

4.3 Stiffness Coefficient:

The stiffness of porous journal bearing is described as the rate of variation of applied load on the bearing concerning the thickness of the nano-oil film. The coefficient of stiffness is mainly get effected by the film pressure of nano-lubricant present inside the PJB. The dissimilitude of the coefficient of stiffness with the bearing number is presented in Fig. 8. This figure also shows a comparative analysis of present results and results of Ref. [11]. The components of stiffness coefficient, i.e. K_{xx} and K_{yy} of the present analysis are improved as compared with the same of micropolar fluid [Ref. 11]. The viscosity of nano-fluid is more than that of micropolar fluid, thus directly make an impact on film pressure and simultaneously on the stiffness coefficient.

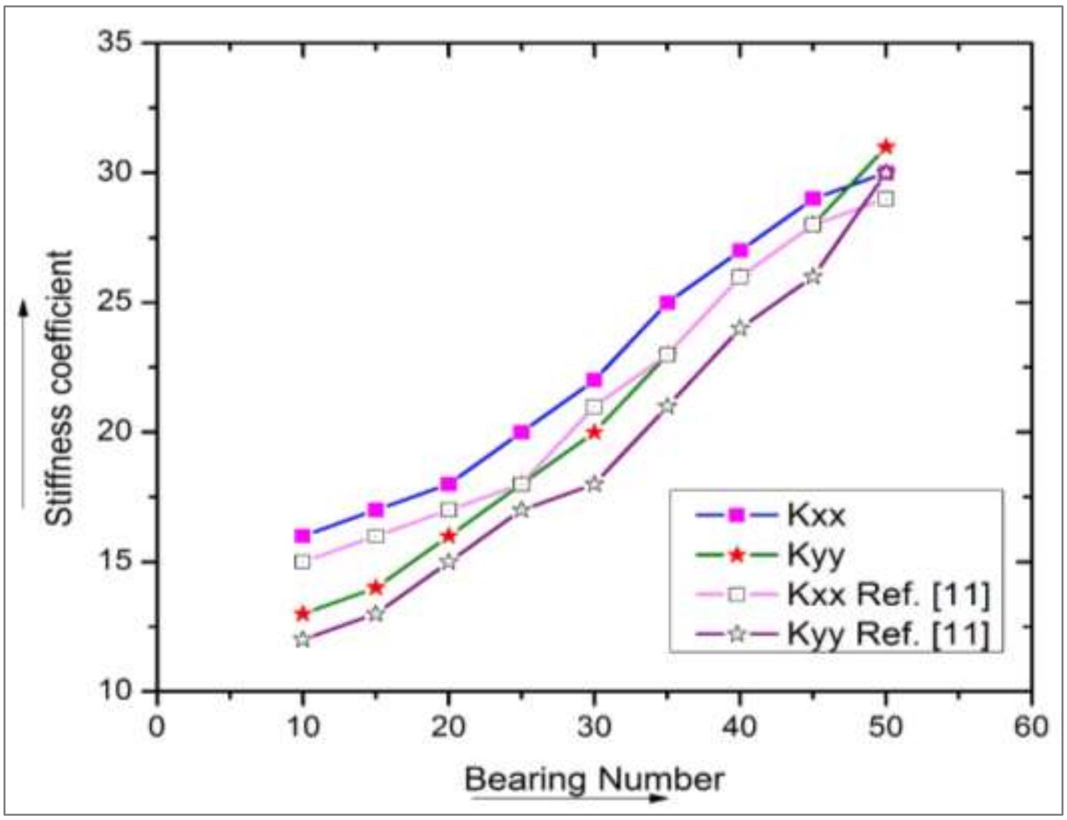

Figure 8: Deviation of the stiffness coefficient with different bearing number and validation of the obtained results with the results of Ref. [11].

The influence of effective volume fraction of nano-fluid and feeding parameter of bearing on the stiffness coefficient of the said PJB is illustrated in Fig. 9 and Fig. 10. It is also perceived from Fig. 9 that the stiffness coefficient increases with the enhance in effective volume fraction because it is related to the viscosity of nano-fluid and even to the pressure of lubricant film. A simple observation is that the viscosity of nano-fluid mainly depends on two parameters, such as maximum particle packing fraction and effective volume fraction of nano-fluid. Figure 10 is also depicted that the stiffness coefficient enhanced with the increase in bearing number with respect to different bearing feeding parameter. It is a parameter of PJB which is directly proportional to the permeability of porous medium and also inversely proportional to the nano-oil film thickness of the journal bearing. So, the coefficient of stiffness is also get influenced by the variation of bearing feeding parameter.

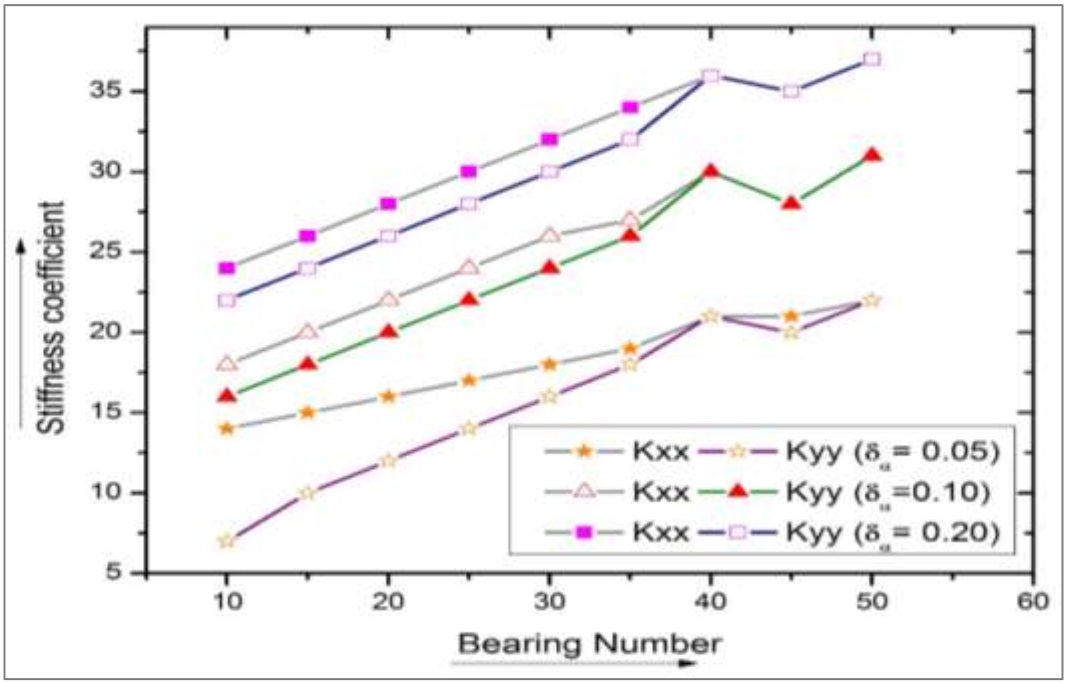

Figure 9: Influence of effective volume fraction (δ_a) on the components of stiffness coefficient with different bearing number (ξ).

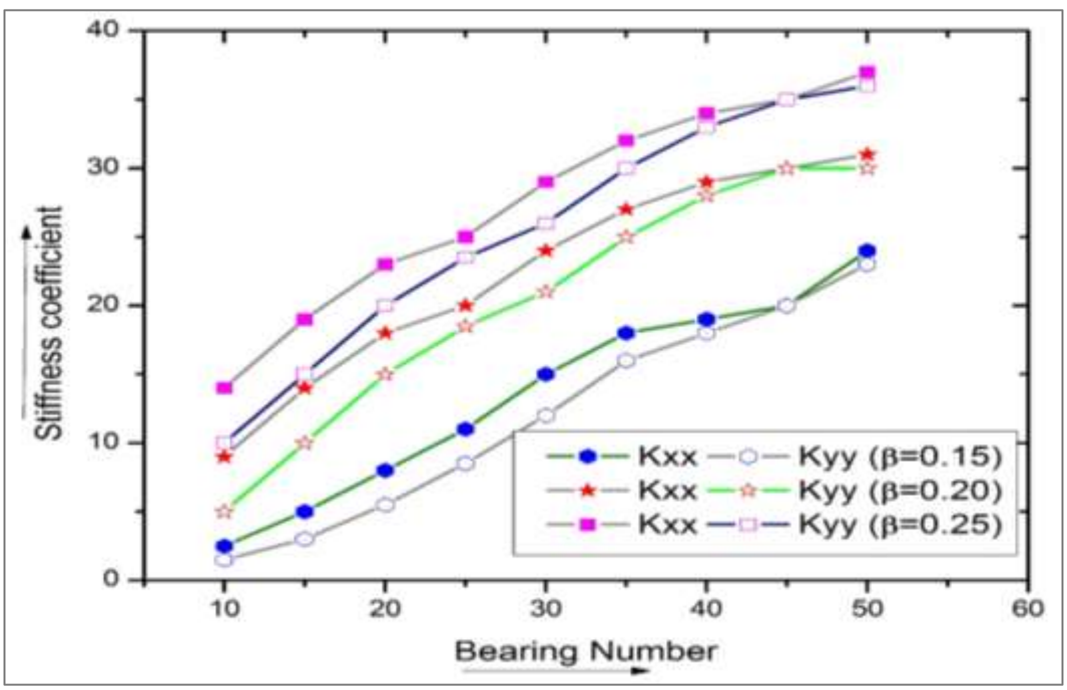

Figure 10: Variation of the components of stiffness coefficient with the feeding parameter of bearing (β) and different bearing number (ξ).

Conclusion:

The present study theoretically evaluates the influence of nano-lubricant on the performance of single-layered PJB. A modified Reynolds equation is developed in consequence of modified Darcy's Law and also by modified Krieger-Dougherty viscosity model. The composition of nano-fluid resulted in a significant increase in viscosity comparing to micropolar fluid and also other Newtonian fluids. Therefore, the use of nano-lubricant improves the performance characteristics of the porous journal bearing under our investigation. The major conclusions may be made from theoretical analysis and observations are noted as follows:

- The load-bearing capacity of the single-layered PJB increases 3% to 5% on the application of nano-oil as a lubricant as compared with the same of non-Newtonian micropolar fluid. The reason is contributed by the size of the additives of nano-fluid, which is much smaller than that of micropolar fluid.

- The size of nanoparticles (1-100 nm) present in nano-lubricant enhances the viscosity of the lubricant and simultaneously increases the stiffness coefficient (2% to 4%) and volume flow rate through the layer of porous medium.

- The bearing feeding parameter (β) of PJB is found mainly effected by the porosity of the porous layer. Thus it may be concluded that the volume flow rate, load capacity and stiffness coefficient are also depend on the permeability coefficient of the porous layer.

- The load capacity of journal bearing under the present investigation is improved by 5% to 10% with the use of nano-lubricant as compared to Newtonian lubricant.

Even though there might be few disadvantages of porous journal bearing, but it can be attended and rectified in future work to improve its efficiency. The performance of such bearing can be substantially improved by modifying its architecture, porous pad design and materials of the porous bushing.

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Disclosure statement:

a. Funding

For this research work, no financial support is received from any source.

b. Conflict of Interest

The authors declare that they have no conflict of interest.

c. Availability of data and material

The data used in this research work has been placed in its appropriate place.

d. Code availability

No code is used to pursue this work.

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Appendix-I

Notations:			
$\boldsymbol{c}$	Radial clearance	$\boldsymbol{\theta}$	Circumferential co-ordinate $= x/R$
PJB	Porous Journal Bearing	$\boldsymbol{x, y, z}$	Co-ordinates in Cartesian form
$\boldsymbol{e}$	Eccentricity	$\boldsymbol{\gamma}$	Absolute viscosity
$\boldsymbol{\varepsilon}$	Eccentricity ratio $= e/c$	$\boldsymbol{k_x, k_y, k_z}$	Components of permeability coefficient
$\boldsymbol{L}$	Bearing length	$\boldsymbol{p^*}$	Pressure inside the porous layer
$\boldsymbol{R}$	Radius of the journal	$\boldsymbol{v^*}$	Velocity of fluid flow through the porous layer
$\boldsymbol{H}$	Thickness of porous layer	$\boldsymbol{\xi}$	Bearing number
$\boldsymbol{h}$	Nano-fluid film thickness	$\boldsymbol{\alpha}$	Permeability parameter
$\boldsymbol{\overline{H}}$	**H** in non-dimensional form	$\boldsymbol{K_{xx}; K_{yy}}$	Coefficient of stiffness
$\boldsymbol{\overline{h}}$	Non-dimensional film thickness	$\boldsymbol{V}$	Nano-fluid film velocity
$\boldsymbol{k}$	Permeability of porous medium	$\boldsymbol{t}$	Time
$\boldsymbol{p}$	Nano-fluid film pressure	$\boldsymbol{u, v, w}$	Components of fluid velocity in X, Y & Z directions
$\boldsymbol{\overline{p}}$	$\boldsymbol{p}$ in non-dimensional form	$\boldsymbol{W}$	Load carrying capacity
$\boldsymbol{\delta_a}$	Effective volume fraction of nano-fluid.	$\boldsymbol{M}$	Volume flow rate

$\bar{\boldsymbol{\mu}}$	Relative viscosity in non-dimensional form	$\bar{\boldsymbol{M}}$	Non-dimensional form of $\boldsymbol{M}$
$\boldsymbol{\beta}$	Bearing feeding parameter	$\overline{\boldsymbol{W}}$	Non-dimensional form $\boldsymbol{W}$

Figures

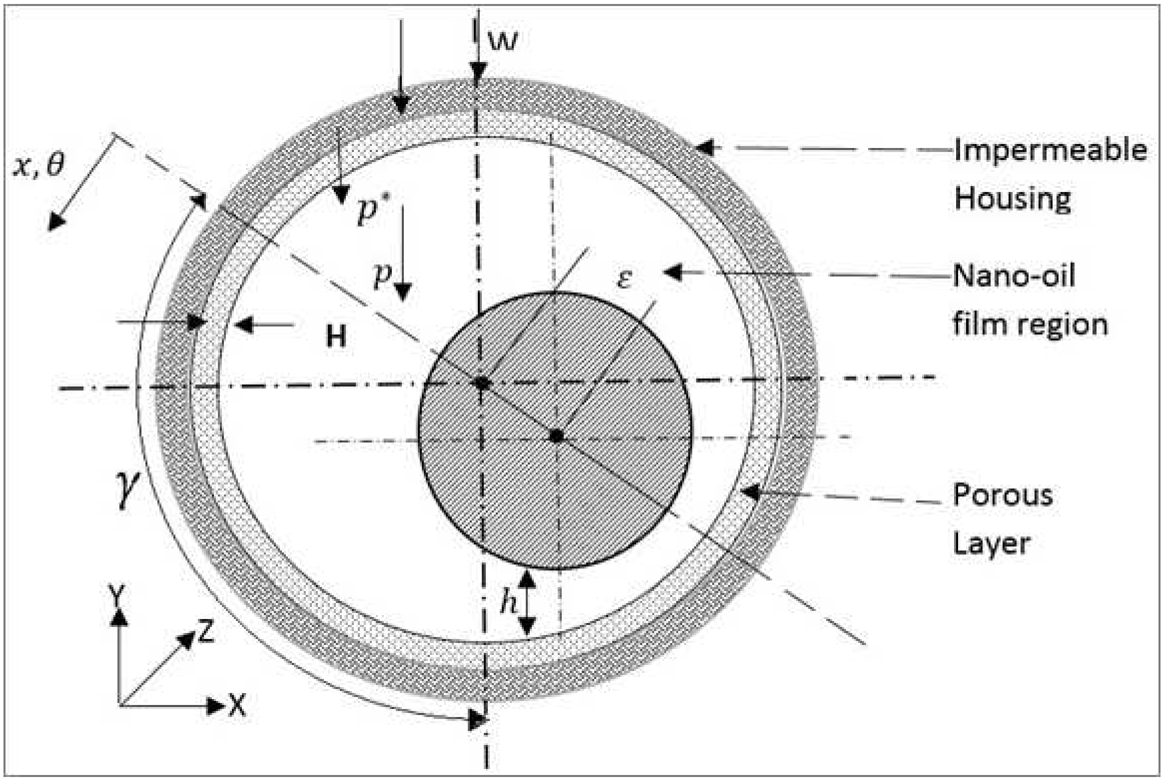

Figure 1

The geometry of single-layered PJB.

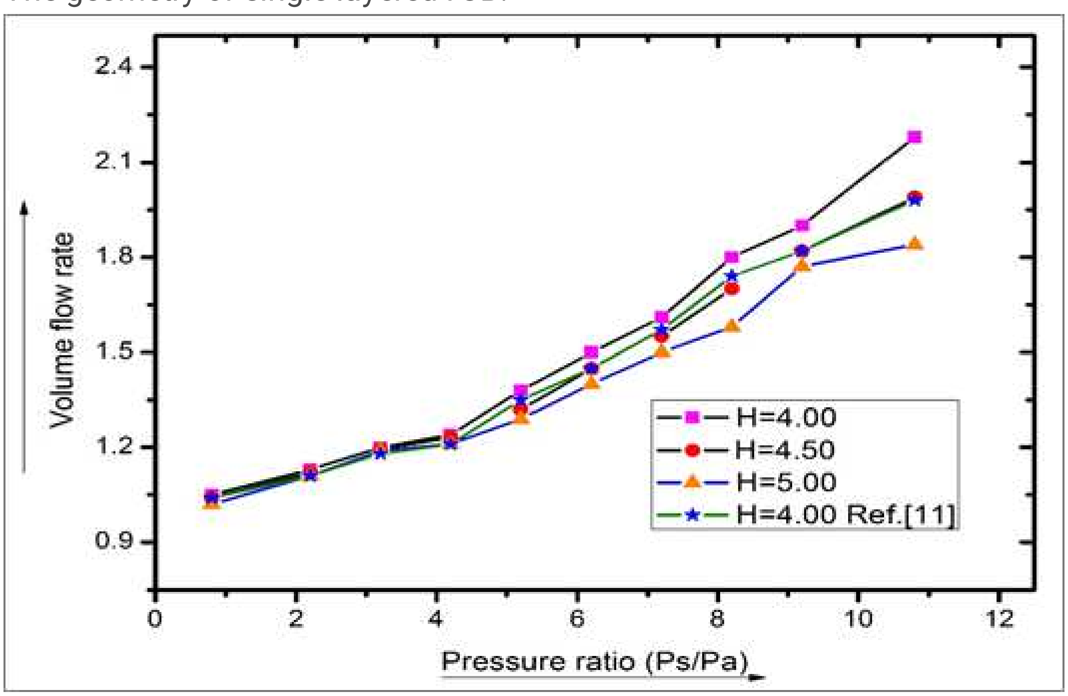

Figure 2

The variation of volume flow rate against pressure ratio for different porous bushing thickness.

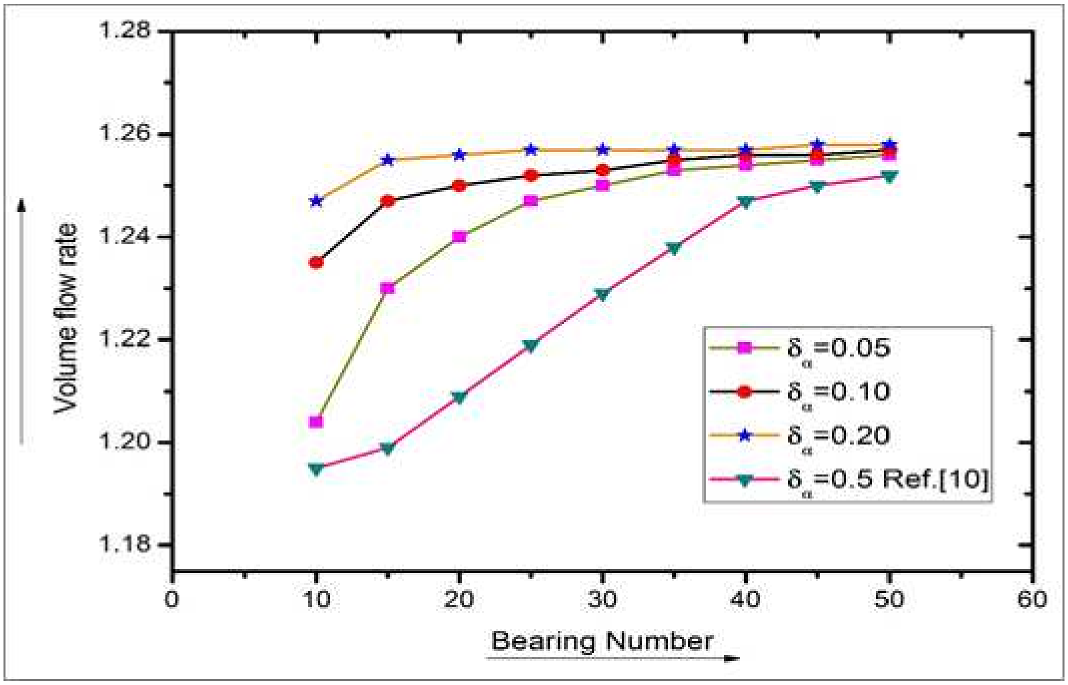

Figure 3

Influence of effective volume fraction (δa) on the rate of volume flow with the bearing number (ξ).

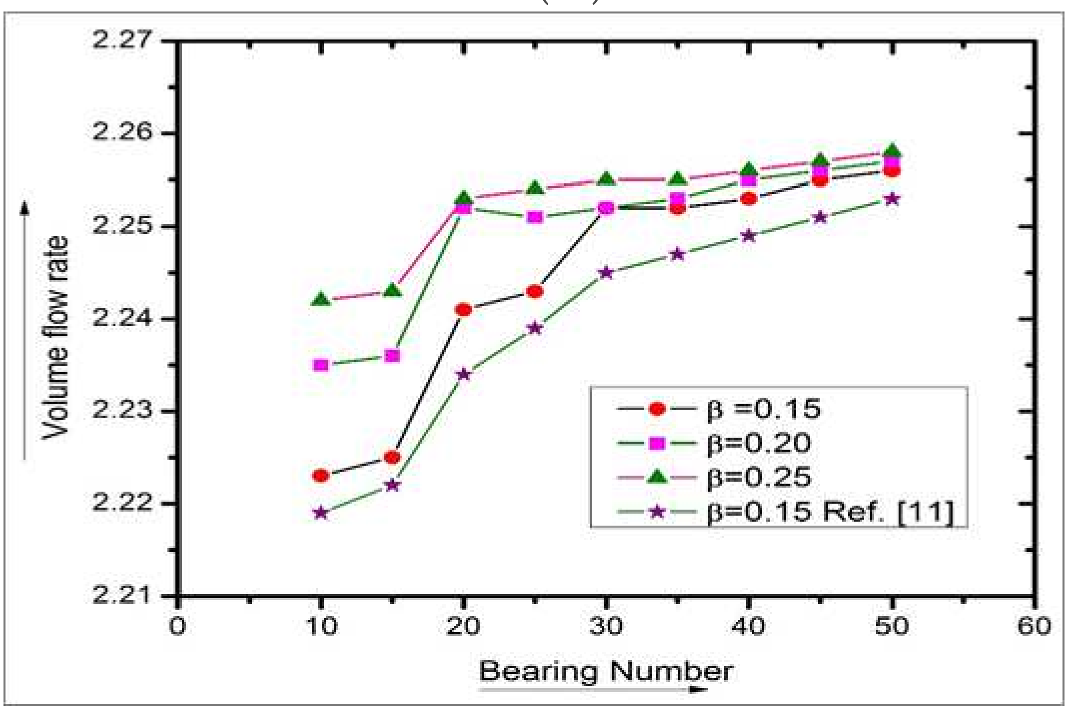

Figure 4

Variation of the rate of volume flow with bearing feeding parameter (β) and different bearing number (ξ).

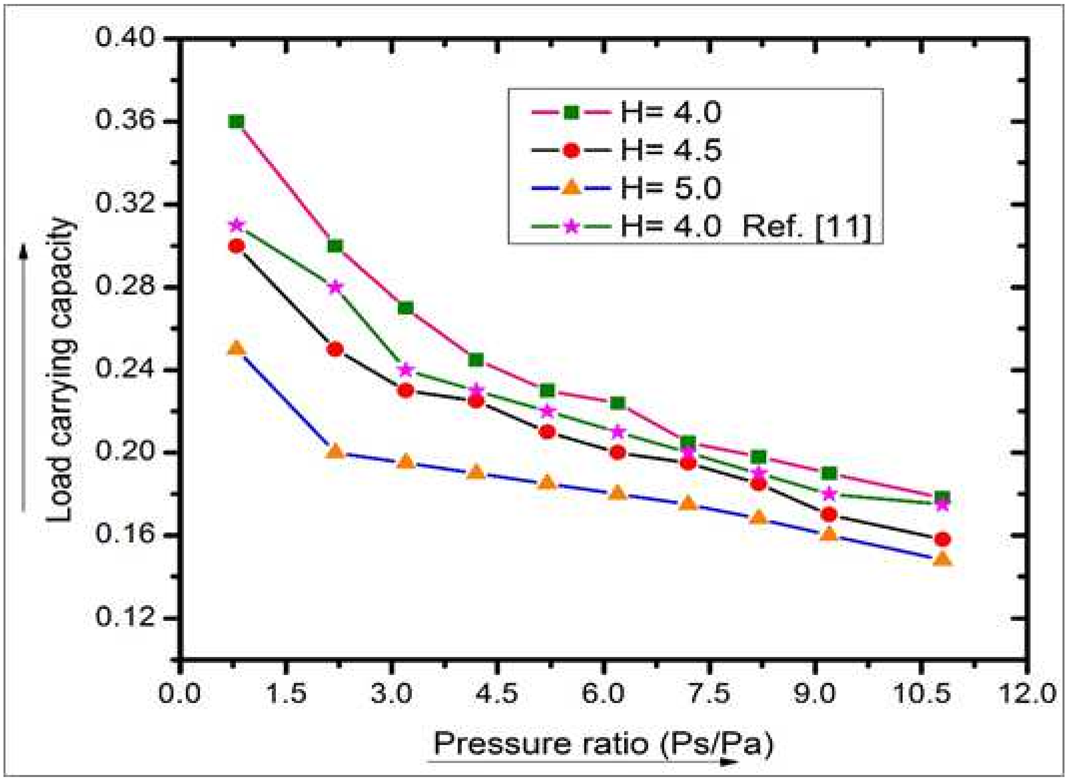

Figure 5

Variation of load carrying capacity against pressure ratio concerning different porous bushing thickness (H).

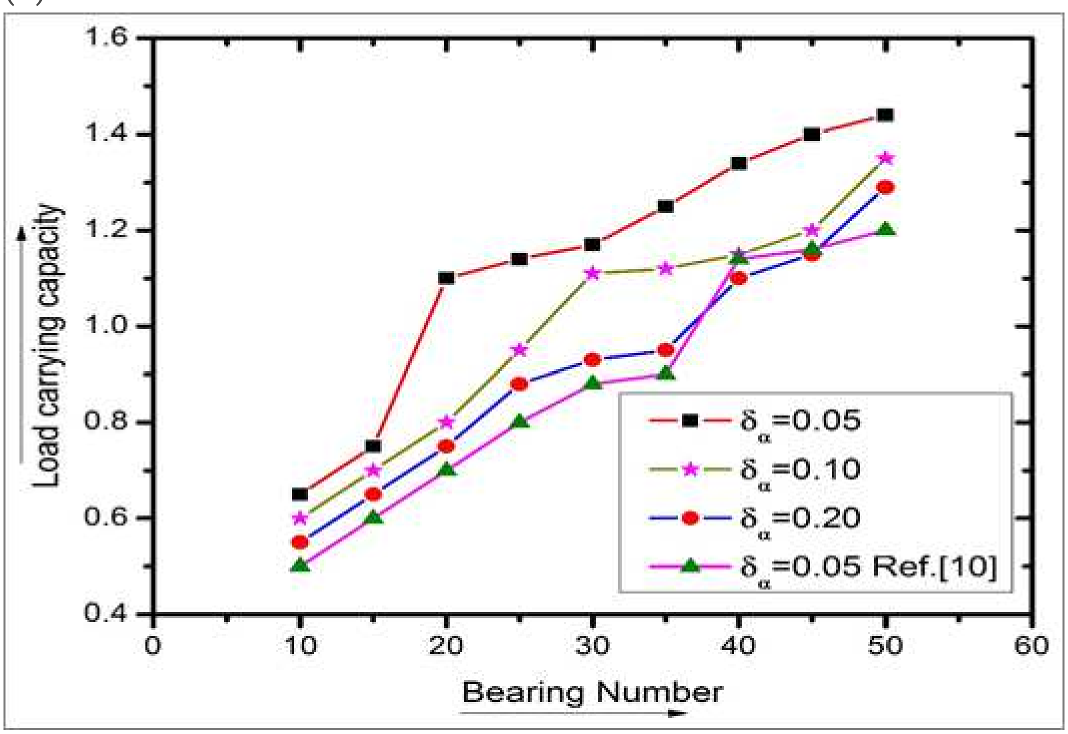

Figure 6

Influence of effective volume fraction (δa) on the load capacity of porous journal bearing with different bearing number (ξ).

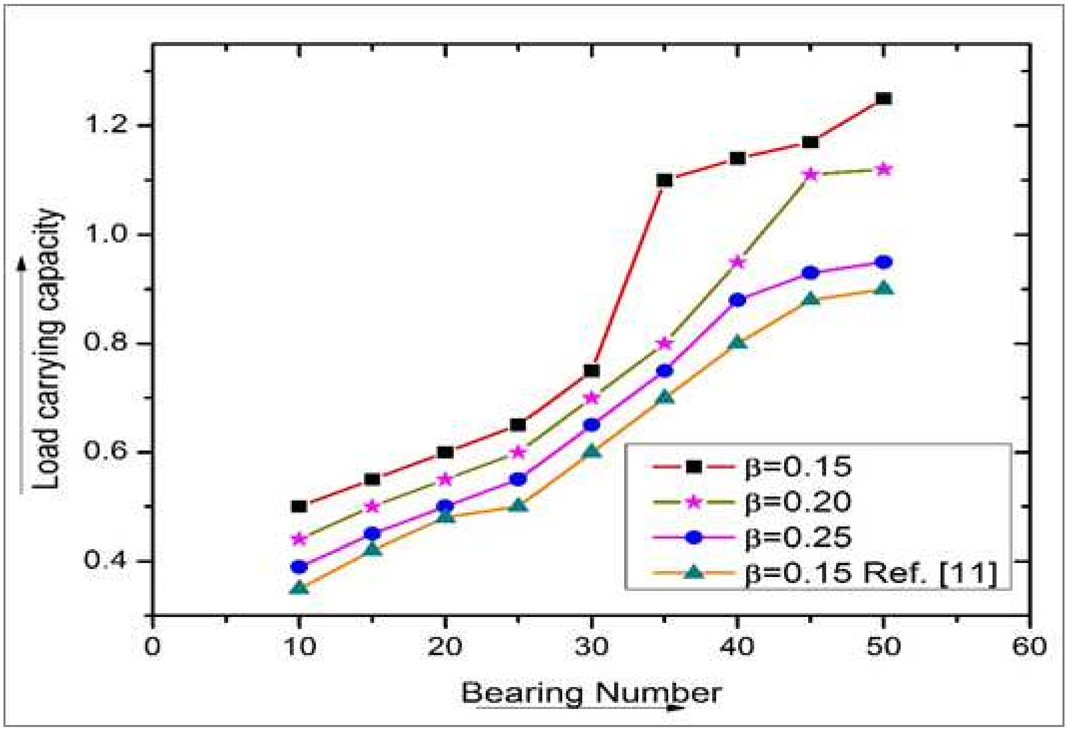

Figure 7

Deviation of load-carrying capacity with bearing feeding parameter (β) and different bearing number (ξ).

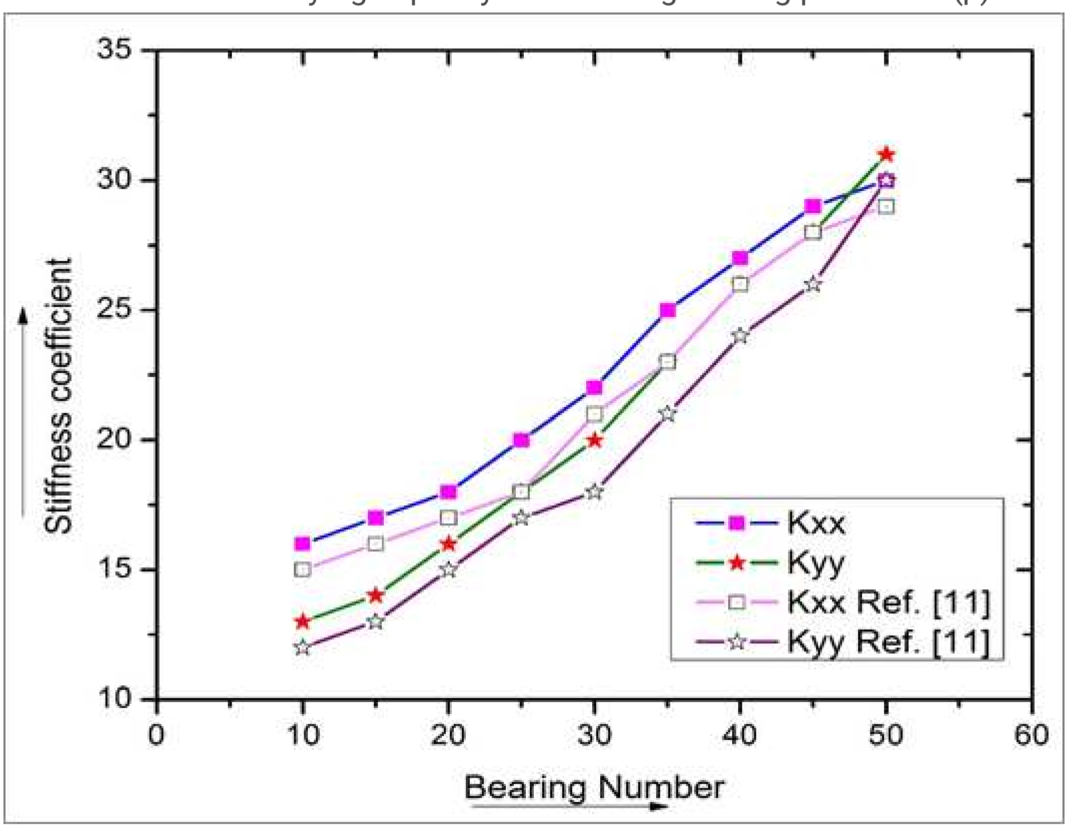

Figure 8

Deviation of the stiffness coefficient with different bearing number and validation of the obtained results with the results of Ref. [11].

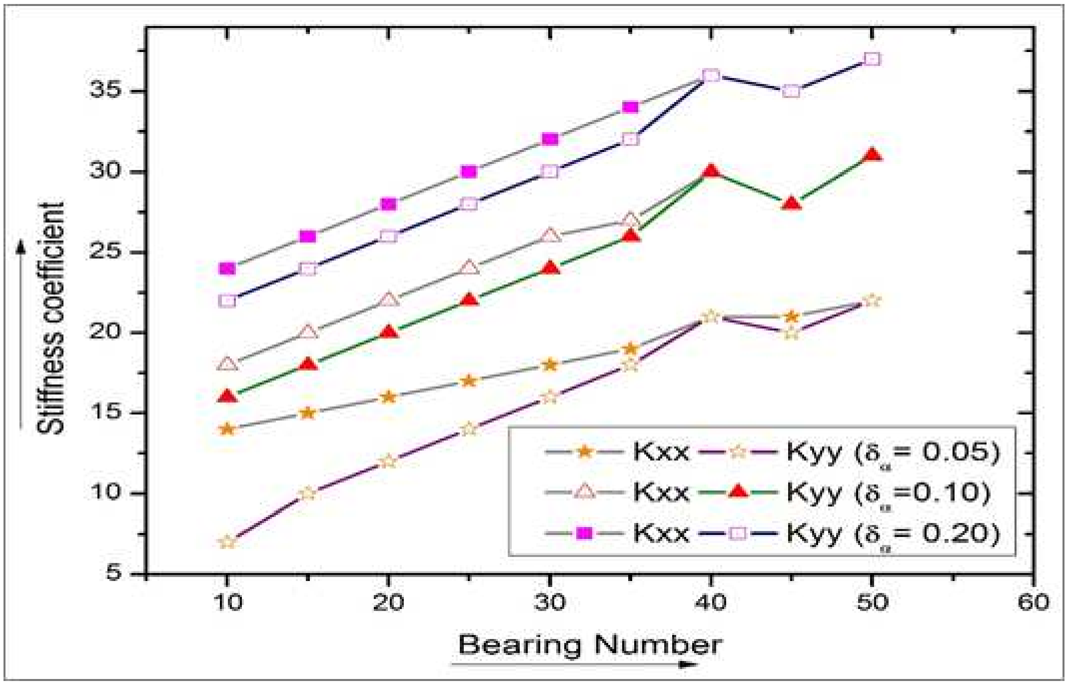

Figure 9

Influence of effective volume fraction (δa) on the components of stiffness coefficient with different bearing number (ξ).

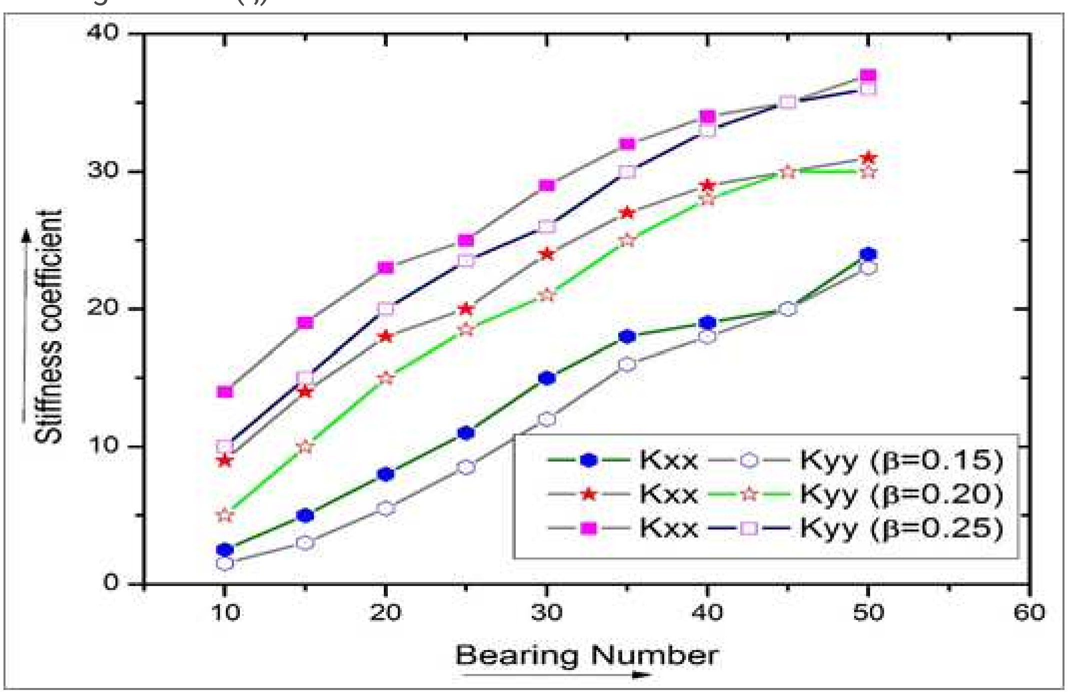

Figure 10

Variation of the components of stiffness coefficient with the feeding parameter of bearing (β) and different bearing number (ξ).