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EFFECT OF THE MAGNETIC PARTICLES CONCENTRATION ON THE FERRO-OIL'S DYNAMIC VISCOSITY IN PRESENCE OF AN EXTERNAL MAGNETIC FIELD IN THE ASPECT OF TEMPERATURE CHANGES

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Abstract

There is presented an effect of the changes of the concentration of magnetic particles included in the ferro-oil on its dynamic viscosity in the presence of external magnetic field in this paper. The study was conducted in the context of temperature's changes.

The authors assume that the concentration of magnetic particles in ferro-oil can significantly affects its basic physical properties as dynamic viscosity, as well as the operational properties of journal sliding bearings ferro-oil's lubricated. The equally significant as the above mentioned properties may affect the external environmental conditions of operation, especially temperature changes. In this context, an important technique's issue appears to determine the principles of selection of optimal concentration of above mentioned particles according to the existing environmental conditions of its operation, or the expectations laid against the operation of the devices.

Rheological studies were carried out on Physica MCR 301 rheometer in the "plate-to-plate" measurement system with an adapter to magneto-rheological studies MRD 180/1T. Thermal stabilization was carried out by a water jacket in a closed chamber and controlling the nature of the magnetic field was conducted by current's changes. Tests were performed for four selected temperature range of 60º, 70º, 80º and 90ºC as regards changes an external magnetic field intensity 0-700 mT. The selected concentrations of magnetic particles in a ferro-oil were 1, 2, 4, 6 and 8%.

Keywords: *ferro-oil, dynamic viscosity, magnetic particles concentration, temperature changes, external magnetic field*

1. Introduction

The issue that has been taken in this study has its own wider context in a research project concerning the analysis of operating parameter's changing of slide journal bearing lubricated by ferro-oils with different concentrations of magnetic particles. The suitability of each oil, as well ferro-oil, for its use in the process of slide bearings lubrication determine the rheological properties, particularly viscosity. This mainly depends on the operating parameters - temperature, pressure or shear rate, but also on their own internal structure, chemical composition expressed inter alia in the concentration of magnetic particles. In the case of ferro-oils substantial impact on the viscosity exerts the external magnetic field variables for the induction value, orientation and type of.

The slide bearing's operating parameters such as friction force, lift force or coefficient of friction depend on directly the dynamic viscosity of the lubricating oil. The values of these parameters provide a operation quality of sliding friction nodes. Further research assessing the impact, as quantitative as qualitative, concentration of magnetic particles to change the ferro-oil's physical properties and consequently, tribological properties of whole the device structure seems to be well founded in that kind of context. There is a requirement to determine the rules for selection of the optimum concentration of above mentioned magnetic particles, depending on the existing environmental conditions of ferro-oil's operation, or expectations put upon against the operation of the device.

2. The effect of temperature on the operation the slide journal bearing

Thermal parameters have a major impact on the slide journal bearing operation. Temperature changes in the sliding friction node can affect in two ways on the bearing structure, including a lubricating oil, which is also regarded structurally.

First of all temperature increase contributes to a decrease of the lubricating oil viscosity. In previous work of the author, among others in [1, 2] has been studied and analyzed the effect of temperature on the ferro-oils dynamic viscosity with different concentrations of magnetic particles in the absence of an external magnetic field. It has been shown that the differences between the viscosity of base oil and ferro-oil with 8% concentration of the magnetic particles ranged from about 2 to 8 times for the results of the shear rate's value of several hundred thousand s^{-1} and from about 3 to 15 times for the shear rate's value to 200 s^{-1}. The larger differences have been cases of lower temperatures, i.e. 0, 10ºC and 20ºC and the smaller ones have been cases of temperatures above 100ºC, 110ºC and 120ºC. The present work expands the area of acquired knowledge about aspects of research involving external transverse magnetic field.

Second, temperature changes in the oil film may change the height of the oil gap due to the bearings pan's temperature deformation and possibly also the deformation of the bearing journal. These deformations lead to a change in the height of oil gap and cause appropriate changes in the value of hydrodynamic pressure, which also results in deformation of the bearing pans. As a consequence, there is another adjustment to the temperature values, which again results in a change of the viscosity of the lubricant and deformations in the bearing oil gap [5, 6].

The essence of the importance of the temperature dependence on physical parameters of oil let illustrate the fact that even the temperature difference of a few degrees can cause a local change of the ferro-oil's dynamic viscosity up to several tens of percent at temperatures close to the nominal bearing operating conditions, to even several hundred in the case of temperatures near start-up state [1, 2]. As it has been shown in [6] precisely of such temperature changes we face in the nodes of the sliding journal friction bearings ferro-oil's lubricated. The temperature difference in the direction of the oil gap's height varies on average in the range a few degrees K with a rather large gradients of temperature changes. Furthermore, local temperature differences occurring between the pan's inner surface and the outer surface of the bearing bush also achieve significant values. While the temperature on the surface of the bearing journal is rapidly equalized during the operation owing to the performance of its rotation, it cannot be neglected very significant temperature changes on the inner surface of the pan with a change in the direction of an angle of wrap. Large temperature gradients in this direction relate particularly points of supplying a fresh oil which has much lower temperature than the oil already used in the oil gap. Very large temperature fluctuations can also be seen on the inner surfaces of the bearing's pans in the longitudinal direction to the axis of the shaft. The temperature gradients are mainly depend on the size and design of the sliding bearing construction.

Complementing this analysis of the changes of the temperature field in the journal slide bearing should also be mentioned ways of heat transfer in the sliding friction nods. In the above case we have to deal with: the transfer of heat between the oil film and the journal, the transfer of heat between the oil film and the pan and its housing and eventually both heat transfer between the oil film and the journal and the pan at the same time. Of course, the heat transfer direction in each of these cases corresponds to temperature gradients. Aforementioned heat transfer occurs mainly by way of conduction. Much less important is the transfer by forced convection and finally negligible by natural convection.

Since that the consideration topic refers to the journal slide bearing ferro-oil's lubricated it's necessary to take into account the effect of external magnetic field on the temperature distribution on the surface of the pan. This field does not only influence directly on the ferro-oil's viscosity change as mentioned above, but also leads to a deformation of the bearing bush. This deformation results in a change of the oil gap height and this effects of changes in the value of hydrodynamic pressure, the lift force, friction force and the coefficient of friction as well. Simulation of such an effect on the above-mentioned operating parameters for journal sliding bearings lubricated by ferro-oil with different concentrations of magnetic particles were performed and presented in previous works [3, 4].

4. Experimental researches

Rheological studies were carried out on Physica MCR 301 rheometer in the "plate-to-plate" measurement system with an adapter to magneto-rheological studies MRD 180/1T. The applied adapter enable to obtain almost homogeneous distribution of magnetic field strength. Thermal stabilization was carried out by a water jacket in a closed chamber and controlling the nature of the magnetic field was conducted by current's changes.

Tests were performed for the constant shear rate value $\theta = 100\ s^{-1}$ and the other for shear rate's changes from 0 to 1000 s^{-1} as well. Regards changes an external magnetic field intensity 0 - 700 mT for the first of these cases. For the other of them adopted value of magnetic field induction amounted B = 200 mT. The obtained results were compared with the adequate tests but for the case of absence of the presence of the magnetic field for B = 0 mT.

In the present study has been measured the viscosity of the ferro-oil made as colloidal mixture of mineral motor oil LongLife Gold of Pennzoil Company with viscosity grade SAE 15W-40 with Fe_3O_4 magnetic particles and a surfactant. Tested ferro-oil has been manufactured by FerroTec in Untersingen (Germany).

The percentage of the magnetic medium (by volume) was 8% and 6%, 4%, 2% and 1%. Average diameter of magnetic particles in studied ferro-oils was 10 nm, while the surfactant content was approximately 15% to 20% vol. Surfactant name was not provided by the manufacturer, as it's his secret.

There are presented the results of ferro-oil's viscosity tests on the graphs below. Fig. 1.a-1.d show the characteristic of viscosity changes for the constant shear rate value 100 s^{-1} for 4 selected temperature values 60ºC, 70ºC, 80ºC and 90ºC. The study involved a ferro-oil's samples with concentrations: 8%, 6%, 4%, 2% and 1% of magnetic particles. The value of magnetic induction coefficient B of the external magnetic field is varied in the range of 0 to 700 mT.

The charts below are presented results of dynamic viscosity changes of the ferrooils with a magnetic particles concentrations respectively of 1%, 2%, 4%, 6% and 8% for the shear rate's changes in the range of 0 to 1000 s^{-1} in the presence of an external transversal magnetic field of magnetic induction coefficient B = 200 mT. The study was conducted for four selected temperatures similar to those characteristic which are value nominal operation of the sliding bearings. The left-hand column shows the corresponding characteristics as for the same temperature values and shear rate changes but in the absence of the participation of an external magnetic field.

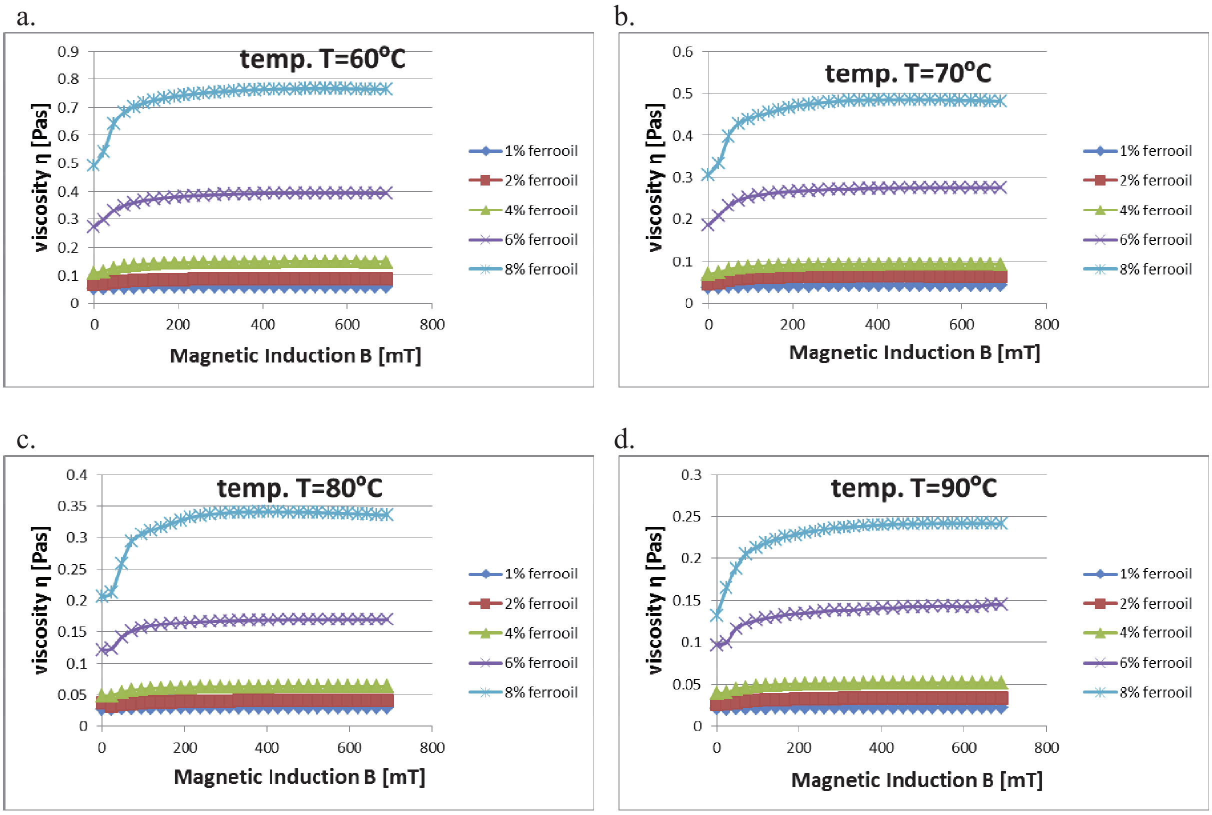

Fig. 1. The characteristics of ferro-oil's dynamic viscosity for the magnetic induction field values in range of 0-700 mT changes in terms of temperature changes

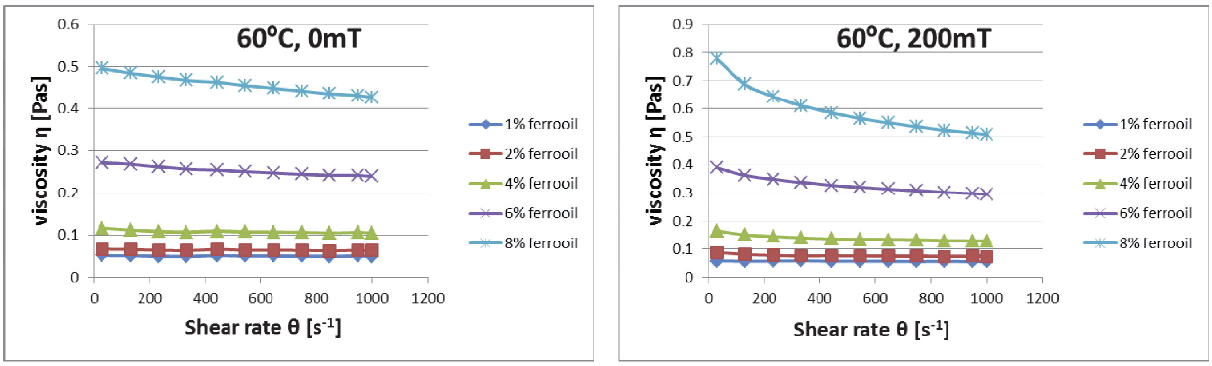

Fig. 2. Characteristics of a dynamic viscosity of 1%, 2%, 4% 6% and 8% ferro-oils for magnetic induction field B=0mT and B=200mT in terms of changes in the shear rate range 0-1000 $s^{-1}$for the temperature t=60°C

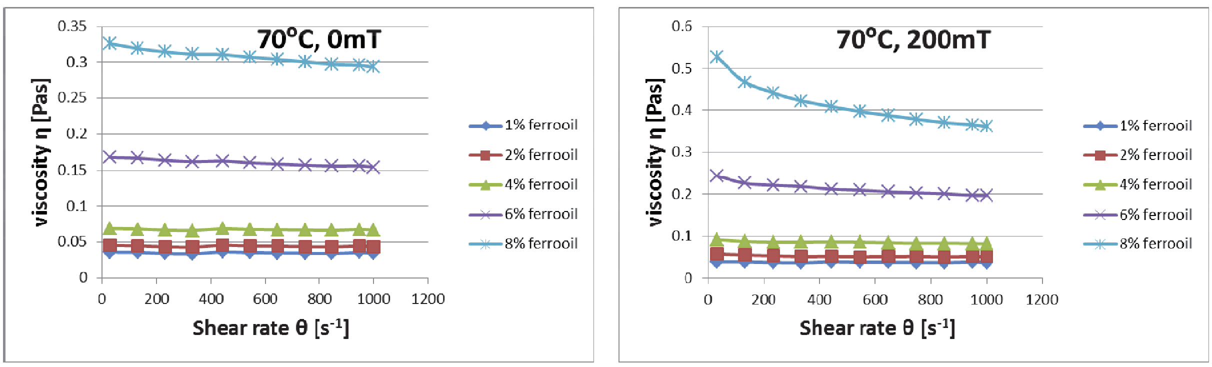

Fig. 3. Characteristics of a dynamic viscosity of 1%, 2%, 4% 6% and 8% ferro-oils for magnetic induction field B=0mT and B=200mT in terms of changes in the shear rate range 0-1000 s-1for the temperature t=70°C

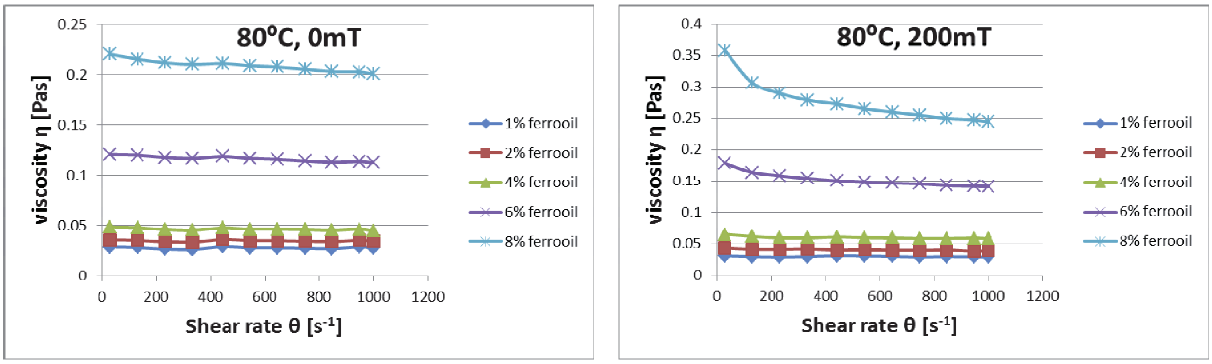

Fig. 4. Characteristics of a dynamic viscosity of 1%, 2%, 4% 6% and 8% ferro-oils for magnetic induction field B=0mT and B=200mT in terms of changes in the shear rate range 0-1000 s-1for the temperature t=80ºC

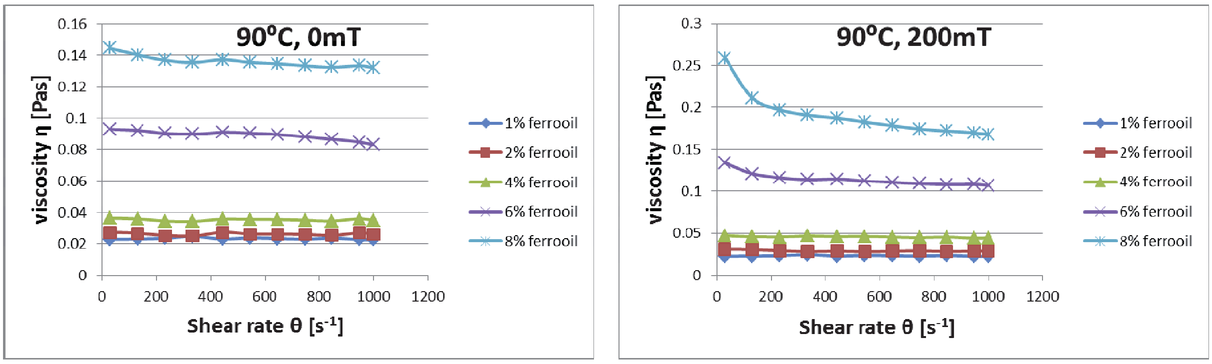

Fig. 5. Characteristics of a dynamic viscosity of 1%, 2%, 4% 6% and 8% ferro-oils for magnetic induction field B=0mT and B=200mT in terms of changes in the shear rate range 0-1000 s-1 for the temperature t=90ºC

3. Observations and conclusions

As a result of the study it can be concluded that the addition of magnetic particles in the ferro-oil, under the presence of an external magnetic field, contributing to the growth of its dynamic viscosity average of more than 10-fold between the lowest 1% concentration, and the highest one 8%. Increase the value of the order of 12.85 times relate the lower temperature of 60°C, and slightly the smaller, i.e. 10.62 times the highest temperature of 90°C.

With the increase of value of the magnetic induction vector of external magnetic field experiences a strong increase in the value of the ferro-oil's dynamic viscosity, which stabilizes at a certain level of saturation near of the induction vector value B = 200mT. This phenomenon is more evident for the higher concentration of the magnetic particles in ferro-oil, in this case for the concentrations of 6% and 8%. That shape of the characteristics is consistent with the explanation posed in [7], which implies that with increasing magnetic field strength is gradually organizing directional settings of magnetic particles in the ferro-oil in accordance with the direction of force field vectors, which is responsible for the increase in the value of its viscosity. This phenomenon takes place until the complete molecular order. Therefore, a further increase in intensity have exhausted all their any effect in this matter. The other hand it appears the fact that a particular phenomenon affirmation for ferro-oils with higher concentrations of magnetic particles is responsible for such dense packing of magnetic molecules in the colloidal mixture, that followed by interaction of the physical and chemical properties between different particles which provide an additional resistance to the ordering action of magnetic field.

The increase in temperature from 60ºC to 90ºC with the presence of an external magnetic field causes a decrease in ferro-oil's viscosity of 2.62 times for the concentration of 1% to 3.17 times for the concentration of 8%.

The mere presence of an external transversal magnetic field contributes to the ferro-oil's viscosity a few dozen percent for all tested concentrations. Higher values of these viscosity increases relate situations when the research was carried out at lower temperatures. In addition, it can be seen that the above mentioned growth decreases with increasing of shear rate, which probably contributes to the tearing of organized layers of magnetic particles.

Finally, it should also be noted that the obtained results are at the moment mainly the comparative value due to the fact that the study needed to operate their in 'plate-plate' system. When measured for non-Newtonian fluids, and ferro-oil exhibits such a nature under the influence of external magnetic field, it is required to use Weissenberg-Rabinowitsch corrections [8] in order to obtain actual values of shear rate, and related characteristics of ferro-oil's dynamic viscosity.

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