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

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Abstract

The purpose of this study is to determine the effect of changes in the concentration of magnetic particles in ferro-oil to change its physical properties, in particular the dynamic viscosity in a constant external magnetic field in terms of changes in shear rate and changes in the intensity of that field.

Rheological studies were carried out on Physica MCR 301 rheometer in the "plate -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 shear rate's changes from 0 to 1000 1/s 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% and the tested ferrofluid was product of FerroTec of Unterensingen (Germany), which is a mixture of colloidal mineral motor oil Penzzoil's LongLife Gold's SAE 15W-40 with Fe_3O_4 magnetic particles and the surfactant.

The paper presents, in the form of graphs, the changes of ferro-oil's dynamic viscosity as a function of shear rate and concentration of magnetic particles in the aspect of external magnetic field's intensity changes.

The results of research were also subjected to analysis. The obtained characteristics of ferro-oil's viscosity show clear evidence of non-Newtonian properties of the liquids. There is observed progression of these properties with increasing of magnetic particles concentration. This fact indicates the essential effect of the addition mentioned particles to the change of the ferro-oil's viscosity characteristics.

Keywords: *ferro-oil, dynamic viscosity, magnetic particles concentration, rheometer, slide journal bearings*

1. Introduction

The problem of lubricating oils and more broadly entire lubricating systems is a very important issue in the design and operation of many technical devices, including, in particular, slide journal bearings. To ensure the quality of the lubricating oil of appropriate, necessary physical and chemical properties is oftentimes the key to achieve the expected effect of these technical devices operating. Consequently, the image of the important role, which the lubricants perform in operation, is the evolution of their perceptions and their current treatment in the literature studies as equal structural components of the devices themselves. From that perspective and a specific different "philosophy" in the operational issues is only one-step to adequate "philosophy" of the design issues. In this kind of aspect, it is no longer just selecting a suitable lubricating oil property to device working expectations but much more – designing operating properties of the device by forming the tribological characteristics with the participation of lubricants.

2. Operational conditions of the ferro-oils

The "subjective" treatment of lubricating oils in the construction of technical systems generates additional expectations that are impossible to put on them. In particular, it will be the susceptibility of their characteristics controlling possibility depending on the existing operating conditions. In this case, we can even talk about using of intelligent lubricants agents. One of these liquids which is already sometimes introduced to the technical structures, which require special arrangements, is ferro-oil. The contained in it additive of the magnetic particles makes it becomes an excellent ferromagnetic under the influence of an external magnetic field, and thus has a strong sensitivity to changes in its viscosity due to changes in the intensity of the above magnetic field. This property provides possibility to introduce technologically advanced design solutions, which combine in a common system of precision mechanical equipment ferro-oil lubricated and modules of oil physical properties controlling and consequently the tribological characteristics of friction pairs and finally utility properties of the devices themselves.

It is not possible to completely disregard the reflections on the physico-chemical properties of ferro-oils to the earlier diagnosis and determine of their operational condition. In principle operational conditions of each component of the device, including ferro-oil lubricants treated structurally, can be divided into internal and external. The first ones are related to the ferro-oil itself, and the second on its environment. It is worth mentioning at this point, that in practice, a set of defining operating conditions is never precisely determined because of the complexity and the extent of issues so it consists mostly on par with known factors, partially known, and even completely unknown.

The set of factors characterizing of the internal ferro-oil's operating conditions include:

– operating parameters, ie, physical values characterizing the course of physical phenomena during operation. In the case of ferro-oil which lubricates slide journal bearings there are mainly torque and rotational speed of the equipment in which said bearing is located as well the temperature of associated components – journals and pans of bearings. The main operating parameters of each lubricating oil are the pressure and temperature in the ferro-oil lubrication system. As a specific and characteristic for ferro-oil's operating conditions it should be mentioned parameters characterizing the magnetic field generated by modules of the ferro-oil's viscosity controlling. Oftentimes as a the premise for application of ferro-oil as a bearing lubricant is a wide range of bearing loads or their exceptionally high value,
– physico-chemical characteristics of the media cooperating. In this case, due to the fact that ferro-oil operates in closed systems does not meet solutions which ferro-oil directly come in contact with other media,
– number of starts and relapses of devices in which the ferro-oil's lubricated bearing is placed, but also the number of starts or overdriving an external magnetic field intensity.

Among the factors that determine the ferro-oil's external operating conditions, we should replace:

– features including – constructional, materials, technological and quality of ferro-oil's lubricated bearing and the entire device in which bearing is supported,
– characteristics of the operators,
– characteristics of automation and control systems, in particular the external magnetic field generating system which controlling ferro-oil's viscosity,
– characteristics of closer and farther environment of a bearing in operation as temperature,

humidity, structural vibration parameters, the quantity and composition of impurities, etc. In view of the fact that the ferro-oils remain relatively expensive and technologically demanding lubricants, they are usually employed regard to a really specific circumstances, in extreme an ambient conditions. This is the situation where mechanical devices are forced to operate in a vacuum environment, in the absence of gravity or a strong magnetic or radioactive field.

3. Physico-chemical properties of ferro-oils

Identified working conditions are usually background of device operation and their should be recorded during ferro-oil's selection of specific physical and chemical properties and especially the rheological ones. As the lubricating oil, including ferro-oil has the strictly defined, commonly known tasks in the technical device, such as:
- reduce friction and component's wear,
- remove heat from friction nodes,
- drain out pollutants from friction nodes,
- protection against corrosion or
- sealing of the associated components,

fulfilment of these tasks conditional on specific physico-chemical properties of the lubricating oil and is a priority for the selection.

The most important physical and chemical properties of lubricating oils include, among others:
- viscosity,
- low temperature fluidity,
- the acidic and alkaline numbers,
- density and specific gravity,
- lubricity,
- surface tension,
- specific indicators such as thermo-oxidative and hydrolytic stability, volatility, water content, flash point and freezing point, etc.

Some of these properties, in particular connected with the viscosity, has been separated into group of rheological characteristics and is as a basis for the description of the quality and comparing characteristics of lubricating oils. Viscosity, generally defined as a measure of internal friction of liquids, are most often determined as the dynamic viscosity, and on that basis it is possible to estimate the potential behaviour of lubricant in the friction pair. The purpose of completing the rheological characteristics is to describe the dynamic viscosity variation depending on such parameters as temperature, pressure and shear rate and the reference to the internal physico-chemical structure of the tested oil. In this paper were performed rheological characteristics of ferro-oil's dynamic viscosity variation with shear rate, and the variability of the colloidal mixture's structure which builds ferro-oil were affirmed by the variability of the concentration of magnetic particles in the base oil.

Describing the ferromagnetic properties of ferro-oils, you have to refer to their specific distinguishing them from other lubricant characteristics. In the first instance, it will be above already described the magnetic susceptibility. The addition of magnetic particles to lubricating base oil determines and changes the rheological characteristics of ferro-oil. Usually while discussing effects of chemical structure on the rheological properties of oils, the most significant effect was the increase of viscosity and pour point associated with increase in the average molar mass of the compounds composing oil or branched chain structure of their [1]. In the case of ferro-oil, that impact remains completely camouflaged due to the addition of characteristic structural agents – magnetic particles. Their presence not only makes the ferro-oil susceptible to control its dynamic viscosity, or the right framing it but sometimes even provides the same to keep the lubricant in the oil gap in conditions where conventional lubricants fail. In addition, another important property oftentimes a crucial of the application ferrofluid in technical solutions are its good vibration damping characteristics of allow its use as an anti-vibration and excessive noise factor.

4. Experimental researches

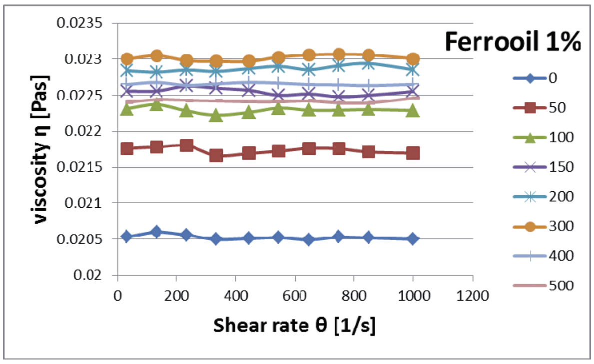
In the present study has been measured the viscosity of the ferro-oil made as colloidal mixture of mineral motor oil LongLife Gold of Penzzoil Company with viscosity grade SAE 15W-40 with Fe_3O_4 magnetic particles and a surfactant. Tested ferro-oil has been manufactured by FerroTec in Unterensingen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

The percentage of the magnetic medium (by volume) was 1%, 2%, 4%, 6% and 8%. 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. The pure mineral engine LongLife Gold oil constituting a base mixture has been studied too.

Rheological studies were carried out on Physica MCR 301 rheometer in the "plate-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 in the 90°C for shear rate's changes from 0 to 1000 s^{-1} as regards changes an external magnetic field intensity 0–500 mT.

The problem of dependence on changes of ferro-oil's viscosity, or more broadly ferrofluid's one, to the shear rate's changes appeared previously sporadically in the subject-matter literature include in the papers of S. Odenbach [5], A. Yu. Zubariev [8], K. Melzner [3] or S. Pytko [6], A. Miszczak [4]. Basically, these studies concerned only minor shear rate of several to tens of s^{-1}. Effect of higher rates to 5000 s^{-1} has been studied by G. Spur and presented in the paper [7]. However, the lack of comprehensive research on ferro-oil can be observed as far as its usefulness for tribological applications is concerned. Selected aspects of these studies related to the influence of the magnetic particles concentration on basic ferro-oil's physical properties has been taken by the author and presented already in the previous papers as [2]. However, these studies were conducted without the presence of an external magnetic field. This paper is a continuation of that study, and partly complements the results so far achieved.

There are presented the results of ferro-oil's viscosity tests on the graphs below. Figures show the characteristic of viscosity changes for the shear rate changes 0-1000 s^{-1} for constant temperature 90°C. The study involved a ferro-oil's samples with concentrations: 1%, 2%, 4%, 6% and 8% of magnetic particles.



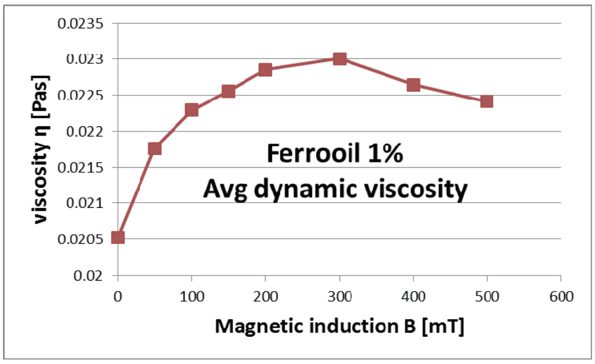


Fig. 1. The characteristics of dynamic viscosity of 1% ferro-oil and averaged values of dynamic versus shear rate changes from 0 to1000 s^{-1} and versus magnetic induction field B = 50, 100, 150, 200, 300, 400, and 500 mT respectively

3. Observations and conclusions

As a result of the study it can be concluded that with the increase of the concentration of magnetic particles in a ferro-oil also increases its value of the dynamic viscosity over 7 times between the concentrations of 1% and 8%. Not directly proportional nature of this change indicates the fact that the viscosity is not only the derivative of increased the molecular weight of mixture, but also results

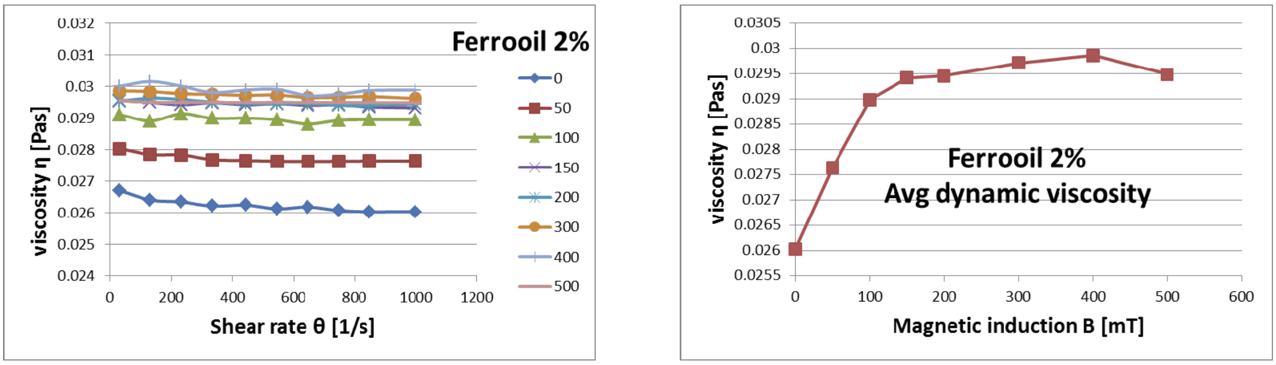


Fig. 2. The characteristics of dynamic viscosity of 2% ferro-oil and averaged values of dynamic versus shear rate changes from 0 to 1000 s^{-1} and versus magnetic induction field B = 50, 100, 150, 200, 300, 400, and 500 mT respectively

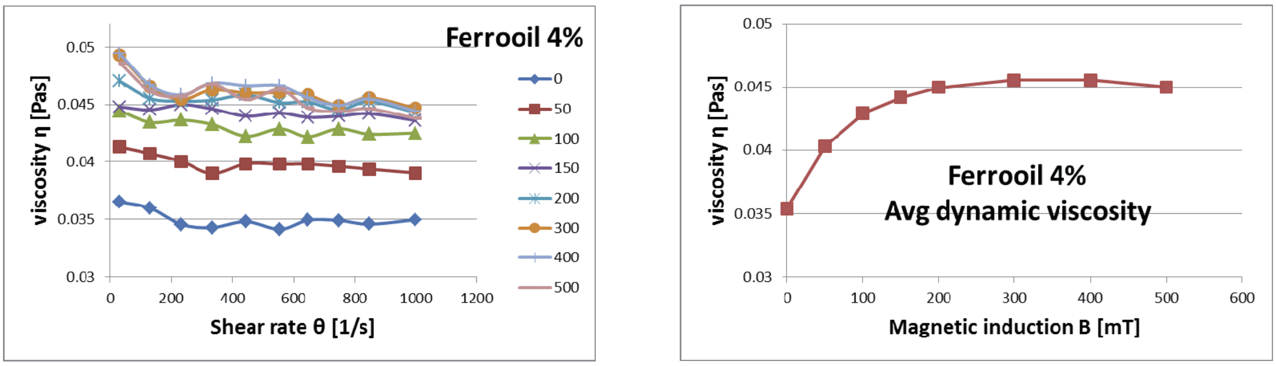


Fig. 3. The characteristics of dynamic viscosity of 4% ferro-oil and averaged values of dynamic versus shear rate changes from 0 to 1000 s^{-1} and versus magnetic induction field B = 50, 100, 150, 200, 300, 400, and 500 mT respectively

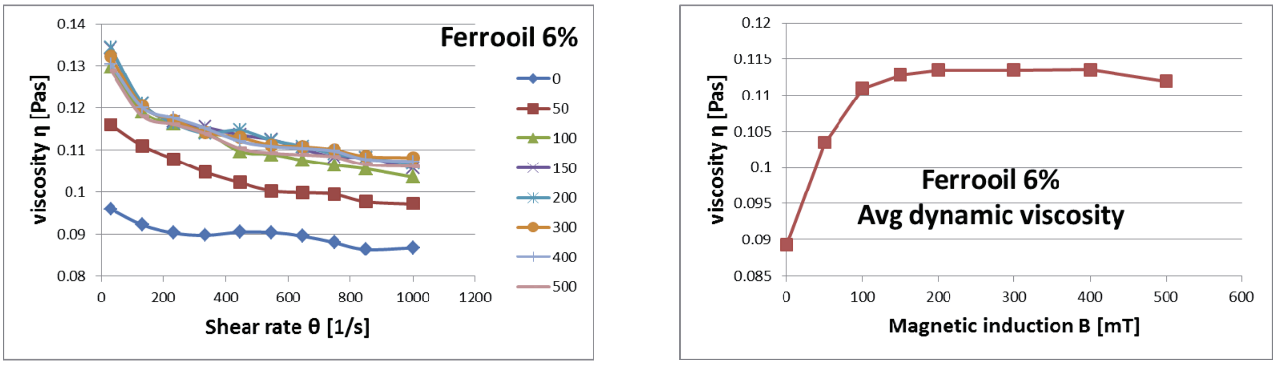


Fig. 4. The characteristics of dynamic viscosity of 6% ferro-oil and averaged values of dynamic versus shear rate changes from 0 to 1000 s^{-1} and versus magnetic induction field B=50, 100, 150, 200, 300, 400, and 500mT respectively

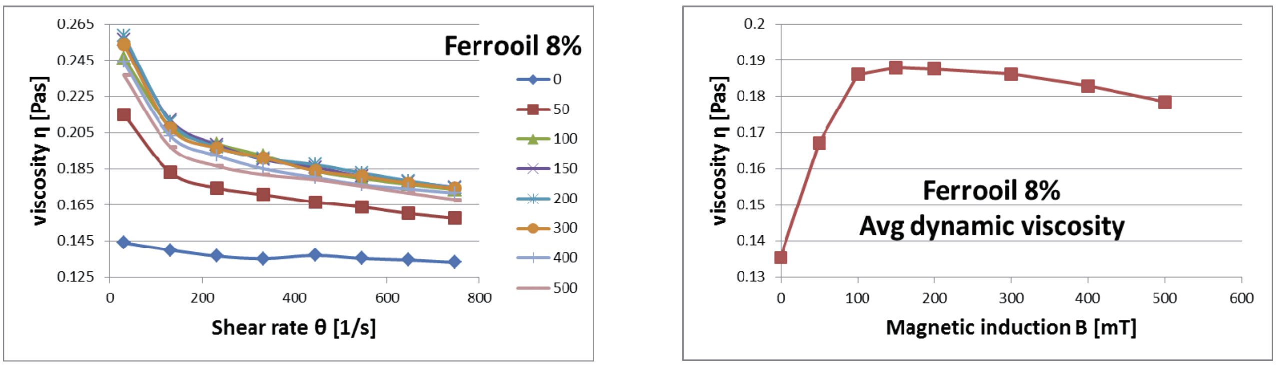


Fig. 5. The characteristics of dynamic viscosity of 8% ferro-oil and averaged values of dynamic versus shear rate changes from 0 to 1000 s^{-1} and versus magnetic induction field B = 50, 100, 150, 200, 300, 400, and 500 mT, respectively

from other characteristics of the internal structure such as the coagulation of magnetic particles in oil, especially at high concentrations.

The presence of an external magnetic field is further affected by the increase in ferro-oil's dynamic viscosity of more than ten percent at a low concentration to almost 50% at the highest values. The largest increase in the viscosity accompanied by a switching magnetic field changed between 0 and 50 mT, and independently of the concentration is approximately 20% of baseline. Further enhancing the value of the external magnetic induction of the magnetic field results in smaller increments viscosities up to stabilize at the level of 200 mT. Probably when the value of the magnetic induction vector takes longer overall directional arrangement of magnetic particles in the ferro-oil, which is responsible for the increase in its viscosity.

It is worth noting that further increase the value of magnetic field even affirms the seeming decrease in viscosity of ferro-oil. However, the observations made during the study suggest that this phenomenon stems from the loss of ferro-oil in the test sample sucked out of the measurement system through targeted field.

Furthermore, with increasing concentration of magnetic particles in the ferro-oil and increases the intensity of the magnetic field has place strong affirmation of the non-Newtonian properties of tested fluid.

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