EFFECT OF CONCENTRATION OF MAGNETIC PARTICLES ON FERROOIL'S DYNAMIC VISCOSITY AS A FUNCTION OF TEMPERATURE AND SHEAR RATE

Marcin Frycz

Maritime University Gdynia
Faculty of Marine Engineering
Morska Street 83, 81-225 Gdynia, Poland
tel.: +48 58 6901335, fax: +48 58 6901399
e-mail: fryczm@am.gdynia.pl

Abstract

Ferrooil's dynamic viscosity changes significantly alter the tribological properties and thus its usefulness as a lubricant of the sliding journal bearings. Due to the fact that the ferrooil demonstrate strong magnetic polarity in the presence of an external magnetic field, it is possible to control the viscosity by means of an external magnetic field just by changing the intensity as well as by changing of the concentration of magnetic particles.

There is presented an effect of the changes of the concentration of magnetic particles included in the ferrooil on the dynamic viscosity in the absence of external magnetic field in this paper. The study was conducted in the context of temperature's and shear rate's changes. In that way, it was also taken into account the influence of external physical conditions of ferrooil's employment.

Tests were performed on HAAKE MARS III rheometer for the shear rate range from 0 to 100000 1/s and temperature of work to 120ºC 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 at a concentrations of: 8, 6, 4, 3, 2 and 1% and the surfactant. Addition of surfactant is to prevent clustering of magnetic particles in the oil.

The paper presents, in the form of graphs, the changes of ferrooil's dynamic viscosity as a function of temperature, shear rate and concentration of magnetic particles. The results of research were also subjected to analysis.

This work is part of a wider study on the analysis of changes in operating parameters of journal bearing ferrofluid's lubricated.

Keywords: *ferrooil, dynamic viscosity, magnetic particles concentration, rheometer, slide journal bearings*

1. Introduction

The subjects taken in this study, as well as the research results presented below, have their context in the broader research project regarding to the analysis of operating parameter's changes of the journal slide bearing ferrooil's lubricated. This analysis is based on numerical and experimental tests of journal bearing's operating parameters, and a control of value of the lubricant's impact in the lubricating gap will take place by changing the concentration of magnetic particles and the change in the intensity of external magnetic field. However, for this purpose is required a prior knowledge of the variability of basic physical ferrooil's properties as his: density, lubricity or viscosity depending on the concentration of Fe_3O_4 magnetic particles, temperature, shear rate and the impact of direction, type and value of magnetic induction. Changes in these properties significantly alter the ferrooil's tribological properties and thus its usefulness as a lubricant of bearings.

In the literature of the subject, in the range of hydrodynamic lubrication of the journal slide bearings forrooil's lubricated, it's can be find a studies in which, there is theoretically recognized the problem of variability of the physical properties of these lubricant's factors. The first of them appeared in the mid-eighties. Precursors in this area were R.E. Rosensweig [10], M.I. Shliomis [12],

N. Tipei [13], A. Ceber [2, 3] and in Poland, also in the eighties, they took this issue R. Janiszewski and K. Wierzcholski [14]. In a slightly later period, that has appeared papers presenting the results of research, in particular characterizing the properties like these above depending on temperature, shear rate and the value, direction and type of external magnetic field, such as A. Ivanov [6], A. Zubarev [15], S. Odenbach [9], K. Melzner [7], A. Miszczak [8]. Made by the author to recognize the state of knowledge indicates that relationships like these about in aspect of concentration of magnetic particles has not been yet elaborated anywhere. It has been the tested ferrooil's dynamic viscosity properties characterized in this paper, depending on the change Fe_3O_4 magnetic particle's concentration in the base oil as well as in terms of temperature and shear rate. This article is part of complex elaboration of research on ferrooil's properties.

Choosing of ferrooil as friction pair's lubricant is usually dictated by any kind of necessity. On the one hand, it may be necessary to obtain the required very high precision of operating the mechanical devices, especially the mechatronic ones. In this case, the application of the lubricant with the properties sensitive to the possibility of controlling them, allows obtaining very specialized and precise operating sliding friction nodes of these devices. On the other hand, it can be an absolute necessity, for example in cases where the device-operating environment is unusual and in many cases, it prevents to use the commonly used lubricants. Such kind of casus is the case when bearings are operating in the absence of gravity, vacuum or in the case of strong magnetic or radioactive fields. Troubles with the maintenance of fluid lubrication also appear in the case of sliding friction nodes loaded forces in a wide range. Controlling an external magnetic field allows in these specific conditions not only change its viscosity but most of all just to keep lubricant in the lubricant's gap. Moreover, an important property which often deciding about the application of ferrofluids in technical solutions are its good damping properties for use as a factor in its anti-vibration and excessive noise.

The very specific ferrooil's structure construction makes them a good ferromagnetic and undergoes a strong magnetic polarity in the presence of external magnetic fields. This allows the influence of the viscosity by means of an external magnetic field by varying the intensity of external magnetic field as well as by changing the concentration of magnetic particles. All of the ferrofluids are obtained by forming a colloidal mixture of microscopic particles of ferromagnetic substances, the most often they're Fe_3O_4, Ge_2O_2 or NiO particles (sometimes also in the form of free metal such as nickel, cobalt and gadolinium), in the base liquid which most often is water, mineral oil, oil synthetic hydrocarbons, fluorocarbons, esters, liquid metals. The diameter of magnetic particles used to be in the range from 5 nm to 20 nm. The special additives, called surfactants, are added to this mixture, such as oleic acid or citric acid, lecithin, TMAH (tetramethylammonium hydroxide) to prevent the merging and sedimentation of magnetic particles. Moreover, the Brownian motions carried out by the magnetic particles also prevent the focusing of the particles and increase their distribution in the mixture

2. Experimental researches

In the present study has been measured the viscosity of the ferrooil 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 ferrooil has been manufactured by FerroTec in Unterensingen (Germany).

The percentage of the magnetic medium (by volume) was 8% and 6%, 4%, 3%, 2% and 1%. Average diameter of magnetic particles in studied ferrooils was 10nm, 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.

Tests were performed on HAAKE MARS III rheometer for the shear rate's range 0-130000 1/s and temperature of work up to 120ºC, according to the ISO 3219 standard for testing of dynamic viscosity by rotational viscometers [11].

There was used the configuration of rheometer chamber with the Peltier's system cone-plate type in the first step of testing. Diameter of the used rotor was d=60 mm and an apex angle of cone was 178°. With that above configuration the characteristics of ferrooil's dynamic viscosity changes have been obtained for the temperature changes from 0 to 120°C every 10K and shear rate Θ from 0 to 200 1/s.

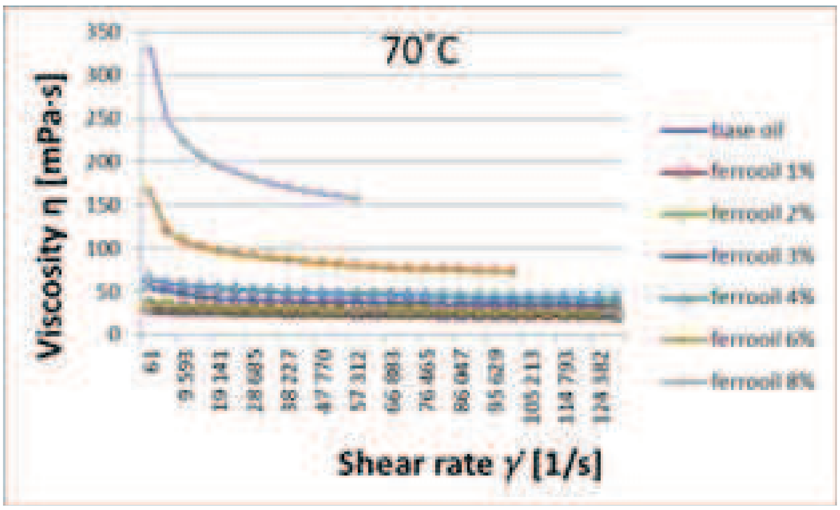
In the second phase of research, the configuration of rheometer with the high shear chamber was used. There was used a cylindrical rotor with a diameter d=21.951mm and the gap width s=0.025mm according to ISO 2555 then. The study was conducted in shear rate Θ changes from 10 to 50 000 1/s for three selected temperatures i.e. 70°C, 80°C and 90°C.

Rheological characteristics among the most fundamental 'tools-property" used in order to describe the quality and comparing of tribological usefulness of the lubricating oils [1]. 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 oil 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 ferrooil's dynamic viscosity variation with temperature and shear rate, and the variability of the colloidal mixture's structure which builds ferrooil were affirmed by the variability of the concentration of magnetic particles in the base oil.

In practice of the maintenance is extremely important that the used lubricant had the smallest possible variability of its viscosity in the range of temperatures which occurring in the operation of the device [5]. Above statement determined the selection of the temperatures at which the ferrooil's dynamic viscosity were examined. Expected values of ferrooil's temperature in slide journal bearing have been estimated at 70º, 80º and 90ºC. At these temperatures being studied in a wide range of shear rate changes from 10 to 130000 1/s, which are also expected in the normal operation of sliding bearings.

The other detailed studies carried out at low shear rate simulated start-up conditions prevailing in the friction node. For a such mode of undetermined operating it seem to be most important the characteristics made for a relatively low temperature that is within the limits of 20-40°C, but due to the relatively small research effort and for the cognitive purpose, they are made in the spectrum of changes of temperature from 0º to 120ºC.

There are presented the results of ferrooil's viscosity tests on the graphs below. Fig. 1 shows the characteristic of viscosity changes as a function of temperature for 70º, 80º and 90ºC and shear rate 10-130000 1/s obtained with the rheometer with the chamber of the high shear. The study involved a ferrooil's samples with concentrations: 8%, 6%, 4%, 3%, 2% and 1% of magnetic particles and the pure base oil as well.



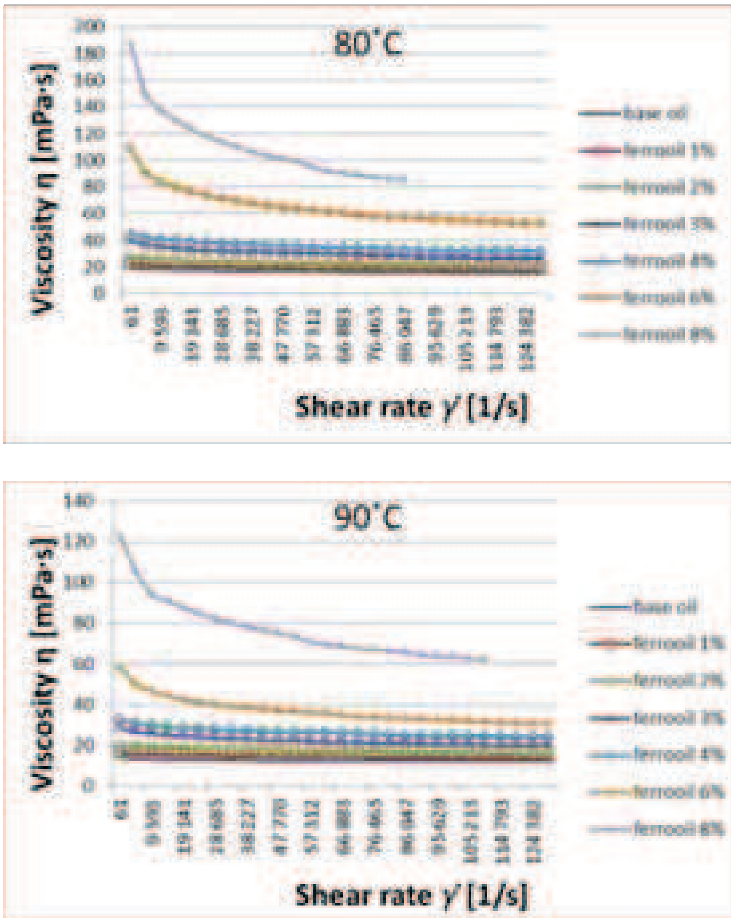
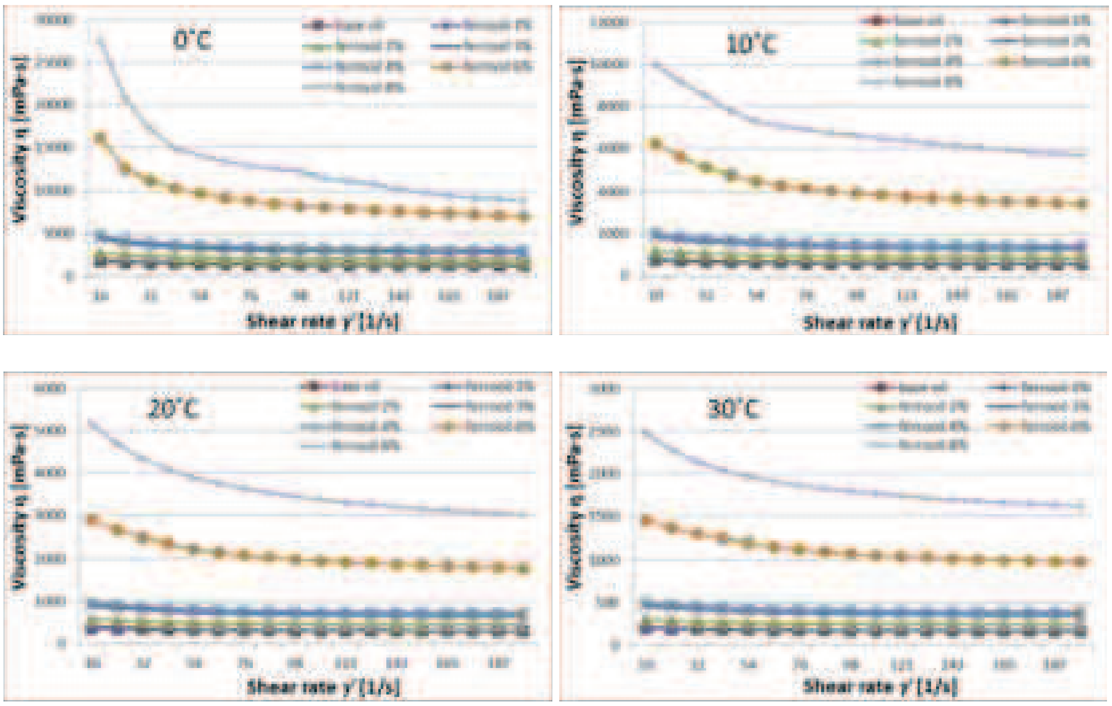


Fig. 1. The change of ferrooil's dynamic viscosity value: a) for the temperature of 70°C, b) for the temperature of 80°C, c) for the temperature of 90°C

Figure 2 shows the characteristic of dynamic viscosity changes as a function of temperature and shear rate obtained by the rheometer with a Peltier's system. Tests were performed for temperatures from 0°C to 120°C at 10 K for low shear rate from 0 to 200 1/s.



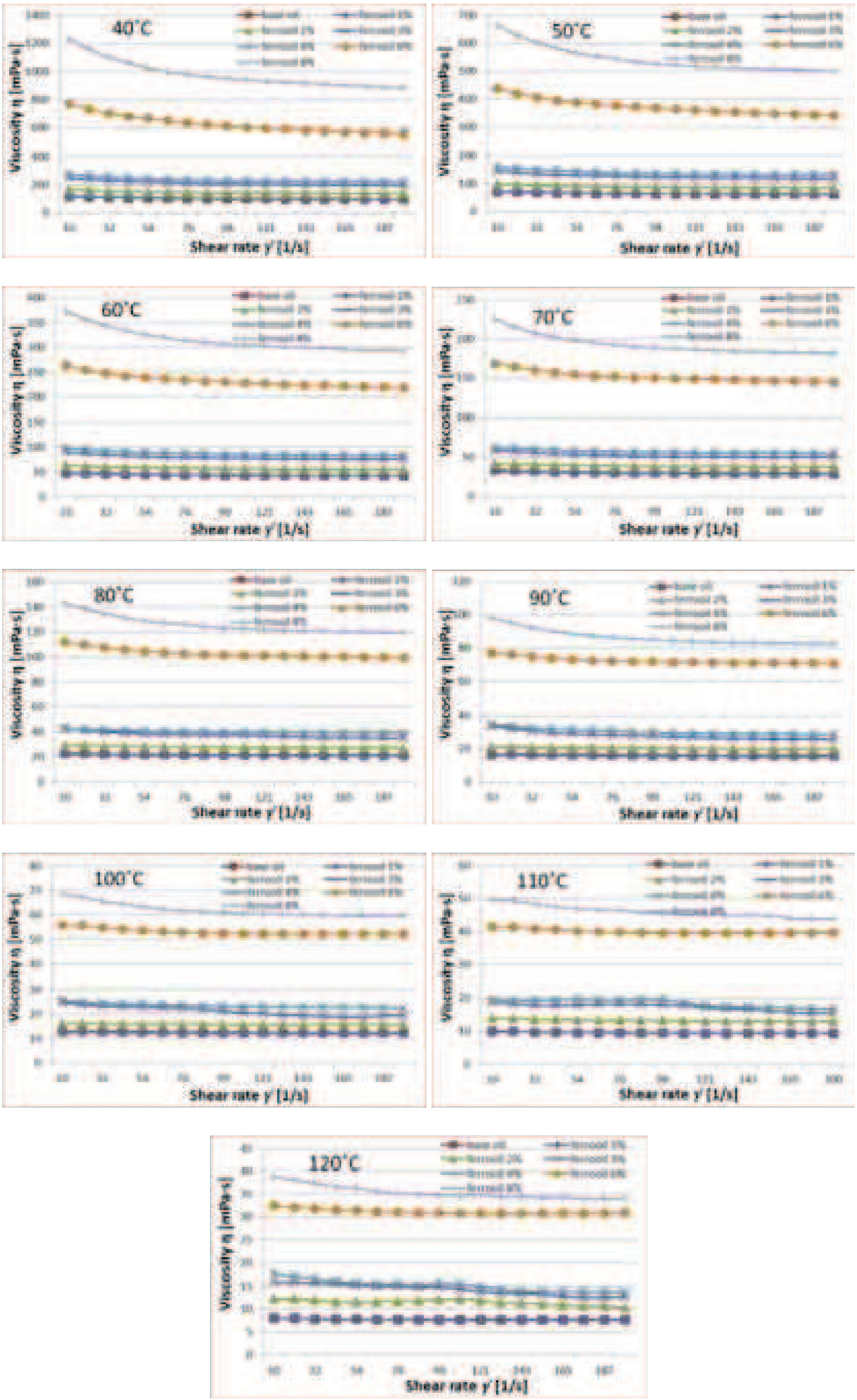
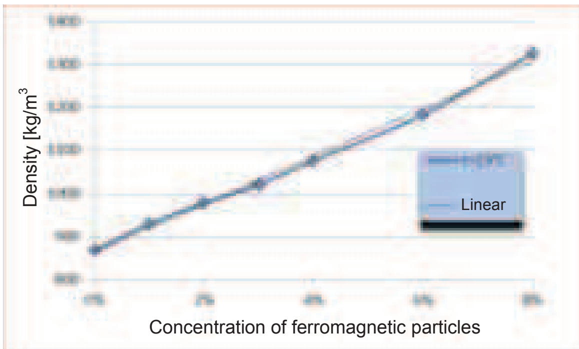


Fig. 2. The change of ferrooil's dynamic viscosity value for the temperature from 0°C to 120°C

3. Observations and conclusions

The aim of this study was to present the impact of the concentration of magnetic particles on the ferrooil's dynamic viscosity. Experimental studies carried out on the rheometer, it seems clear that the presence of magnetic particles in the oil affects the substantial increase in its viscosity. Furthermore, it is demonstrated that increasing the concentration of these particles also causes an increase of dynamic viscosity. Differences between the base oil viscosity and the ferrooil by 8% concentration of magnetic particles ranged from about 2 to 8 times for test results at high shear rate system and from about 3 to 15 times for the results obtained on the Peltier system. Larger differences were observed in cases of lower temperatures. It should be noted that the gradation values of dynamic viscosity is not closely correlated with the increase in concentration of magnetic particles in ferrooil. The different nature of the course of the two properties shown in the following Fig. 3 presenting dependence of dynamic viscosity and density at the selected temperature in terms of concentration of magnetic particles. This suggests the complexity of the phenomenon, which is responsible for the increase in feerooil's viscosity. It is not only derived of increase the molecular weight of the resulting mixture. The author moves towards one of two explanations. On one hand, the nature of the changes may be due to ferromagnetic particles coagulation in the oil at higher concentrations, which hinders the movement of particles relative to each other and leads to an increase in viscosity. On the other hand, it is possible hypothesis that the increase in viscosity corresponds mainly the presence of surfactant, which percentage in the original ferrooils at concentrations of 8% and 6% of magnetic particles was higher than in mixtures with lower concentrations of magnetic particles produced by appropriate dilution of ferrooil by base oil.



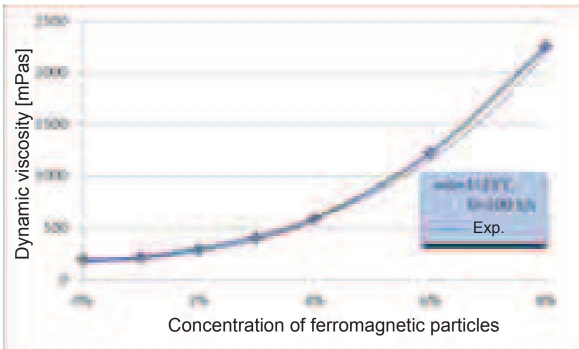


Fig. 3. The characteristics of changes in viscosity and density in terms of concentration of magnetic particles in ferrofluid [4]

Both the results of tests on the Peltier system at relatively low shear rate, and on the chamber of high shear rate at speeds hundreds of times higher, show a change in nature of the oil when its added to the magnetic particles. While the pure base oil showed almost in the completely studied temperature range Newtonian properties, it ferrooil built on the same base oil, has already been affirmed of non-Newtonian properties, viscoelastic. It should be noted, moreover, that the stronger non-Newtonian properties have been observed for the ferrooil's including higher concentration of magnetic particles and for cases when the temperature of the test was lower.

Application the ferrooil as a lubricant in the friction node does not necessarily prove to be advantageous the choice if is not dictated by a pre-specified necessity. Results of this study we can observe that ferrooils, especially those with higher concentrations of magnetic particles as 6% or 8%, show a relatively high variability the value of dynamic viscosity with the temperature and the change in shear rate. Also, at these temperatures, which was established as occurring in normal use the device. From the operational point of view, this situation is unfavourable. The final assessment of the tribological suitability of the ferrooils requires more rheological tests, but in the presence of external magnetic field. Such studies have been planned by the author and will be realized soon.

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