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Experimental evaluation of engine oil properties containing copper oxide nanoparticles as a nanoadditive

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Abstract

Background: The properties of lubricants are mainly the result of adding a material for improving or producing the required properties. Today, different materials with various nanostructures are used as new additives which, because of their unique properties, are used for improving the lubricant's properties. The purpose of the present research is to add copper oxide (CuO) nanoparticles to engine oil and evaluate the produced changes in some of its properties. Also, viscosity, pour point, and flash point of nanolubricants, which are made at different concentrations (0.1, 0.2, and 0.5 wt.%), and also their thermal conductivity coefficient as four quality parameters which are effective in the functionality of engine oil are evaluated.

Results: Upon the obtained results, thermal conductivity coefficient and flash point of nanolubricants with 0.1 wt.% concentration, respectively, had 3% and 7.9% improvement with respect to the base oil. Also, the oil's viscosity, as a very important factor in lubricating issue, at a lower concentration with respect to the engine oil without CuO had no appreciable change.

Conclusion: Among the different methods which have been used for dispersing nanoparticles inside the base oil, using planetary ball mill was determined as the most important method for stabilization of nanoparticles inside SAE 20W50 engine oil. Also, the physical properties of nanolubricants were measured based on the American Society for Testing and Materials standard methods.

Keywords: Copper oxide nanoparticles, Engine oil, Viscosity, Thermal conductivity coefficient

Background

Recent advances and success in chemistry and technology of nano-organic particles with nanosize have provided the possibility of making different metallic oxides. During the past few years, the attention for producing and application of colloid nano-organic particles due to their unique properties such as optical, catalytic, semiconductor, magnetic, and anti-friction properties is continuously developed [1]. Copper oxide nanoparticles are one of the particles with their tribological and anti-wear properties being investigated by some researchers [2,3]. Thottackkad et al. have studied and reviewed the tribological properties of coconut oil, which contains copper oxide nanoparticles, because of very great interest of researchers to plant oil as a lubricant which is used in automobile and also for the purpose of improving its properties. Upon their results, the natural wear and friction coefficient improved and the viscosity of base oil increased with increasing concentration of nanoparticles [3].

With rapid development of nanomaterial technology and stable growth of difficulties which exist for sources of energy, researchers have started to apply nanomaterial technology in the field of increasing heat transfer for the purpose of developing homogenous and stable heat transfer fluids. Nanofluids are produced by dispersing nanoparticles inside typical heat transfer fluids such as water, ethylene glycol, and oil [4]. Recently, an increase in the thermal conductivity coefficient of nanofluids which contain a little amount of metallic particles like Cu or nonmetallic particles like ZnO, Al_2O_3, CuO, and SiC had also been reported. The natural potential of nanomaterials which are dispersed in base fluids for heat

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transfer also has an important effect on the rate of increase in thermal conductivity coefficient of nanofluids. For example, carbon nanotubes, due to their high thermal conductivity coefficient, are known as an ideal material for making nanofluids [5]. Hwang et al. have studied the heat transfer properties of nanofluids in water base and ethylene glycol base which contain CuO nanoparticles and multiwalled carbon nanotubes. They used transient hot wire method for measuring the thermal conductivity coefficient of nanofluids. In the case of nanofluids which contain CuO nanoparticles, their results showed that the increase of nanofluid thermal conductivity in the ethylene glycol base was more than that of the distilled water base nanofluid. Also, the thermal conductivity of distilled water base nanofluid which contains MWCNTs increased at the rate of 11.3% in 0.01 volume fraction [6]. Totally improving the properties of a lubricant is a very important factor for saving total energy given to a mechanical system [7]. Nanoparticles also, due to their unique properties as a new kind of additive material for the purpose of improving the properties of lubricants, are very interesting and have attracted attention [8]. So far, the anti-wear and anti-friction properties of different nanolubricants [9-12] and also the heat transfer properties of fluids which contain different nanostructures [6,13,14] had been studied by many researchers. So, in the present research, we are surveying the effect of CuO nanoparticles on the other properties of engine oil such as viscosity as one of the most important factors which are used for correct selection of the required oil in a lubricating system and also flash point and pour point as the properties which are related to the quality of oil functionality in different work conditions.

Methods

Materials

Copper oxide nanoparticles were made on the basis of the presented method by Karthikeyan et al. [15]. The X-ray diffraction (XRD) pattern of the product obtained is identical to that of single-phase CuO with a monoclinic structure (Figure 1). Further comparison of XRD patterns with the JCPDS file (JCPDS 80–1268) data also confirms the same. By means of XRD, no obvious peaks of impurity were found.

The specifications of the oil used are shown in Table 1. The SAE 20W50 engine oil (Behran Pishtaz, Behran Oil Company, Tehran, Iran) was used as a base fluid. Behran Pishtaz oil is a distinguished engine oil which has been made upon the highest world standards and is suitable for most of today's light gasoline automobiles and heavy diesel vehicles.

Apparatus

A bath ultrasonic (P120 Elmasonic, Elma Hans Schmidbauer GmbH & Co. KGa, Singen, Germany), probe ultrasonic (Syclon Ultrasonic Homogenizer/JY92-IIN, Zhejiang, China), and planetary ball mill (PM100, Retsch, Haan, Germany) were used for opening agglomerated CuO nanoparticles from each other and dispersing them inside the base fluid. Also, we used the KD2 Pro (Decagon Devices, Pullman, WA, USA) for measuring the thermal conductivity of base oil and nanolubricants.

Preparation of nanolubricants

The concentration of nanoparticles has a great effect on the functionality of nanolubricants, with about 0.1 to 0.5 wt.% stated as the optimum concentration for nanoparticles in

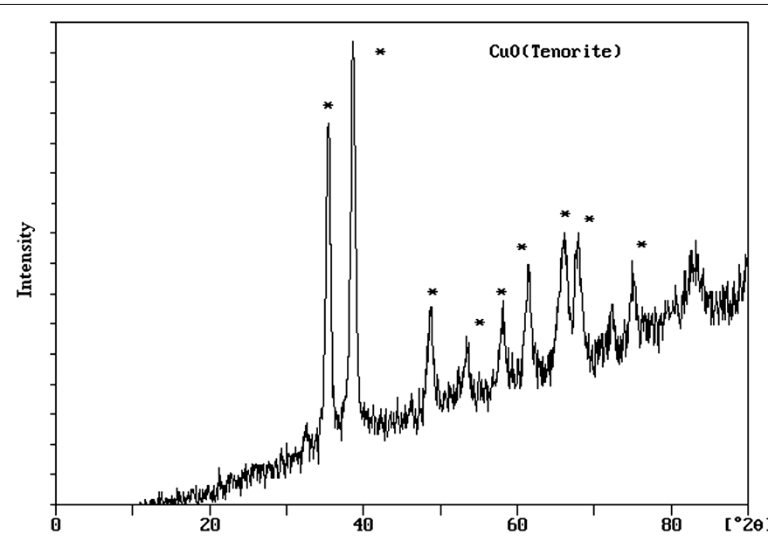

Figure 1 XRD pattern of CuO nanoparticles.

Table 1 Specification of SAE 20W50 engine oil

Specification	Value
Viscosity at 40°C (cSt)	172.11
Viscosity at 100°C (cSt)	19.8
Density at 15°C (kg/m^3)	889
Viscosity index	133
Pour point (°C)	−27
Flash point (°C)	224

most of the investigation works and studies [12,16]. Also, in the present research, for the purpose of evaluating the rate and manner of the effect of CuO concentration on the properties of base oil, nanolubricants were made at three different concentrations of 0.1, 0.2, and 0.5 wt.% by adding CuO nanoparticles to the base oil. Basically, nanofluids are solid–liquid mixtures which are earned from dispersing nanoparticles with sizes smaller than 100 nm inside a base fluid [13]. For this purpose, researchers have used conventional methods which are common in investigation works such as dispersing using a mechanical mixer, bath and probe ultrasonic, planetary ball mill, and surface activation materials. Because the viscosity of the base fluid used in the present research was very high, we used planetary ball mill method for dispersing nanoparticles inside the base fluid. Functional specifications of the planetary ball mill which is used for making nanolubricants are shown in Table 2.

Measuring the viscosity, pour point, and flash point

Kinematic viscosity, pour point, and flash point of the base oil and also nanolubricants, which were made at three different concentrations, were measured on the basis of American Society for Testing and Materials (ASTM) D-445, ASTM D-97, and ASTM D-92, respectively. The accuracy measurements of these parameters according to the ASTM standards are shown in Table 3.

Measuring thermal conductivity

Energy transfer from high-energy particles to particles with lower energy in a material is called conduction, which takes place by the interaction between the particles. Thermal conductivity (K) of fluids is measured as their ability to conduct heat. For this purpose, we used the KD2 Pro equipment which is completely a portable field or laboratory apparatus for analyzing the thermal properties and uses the transient hot wire system for measuring thermal conductivity [17]. Thermal conductivities of base oil and nanolubricant with 0.1 wt.% concentration were measured at 20°C temperature.

Table 2 Functional specifications of ball mill

Specification	Value
Speed (rpm)	300
Time (h)	3
Weight of balls (g)	200
Weight of sample (fluid + nanoparticles) (g)	30

Table 3 Accuracy measurement of ASTM standards

ASTM standard	Accuracy
ASTM D-445	0.26%
ASTM D-92	±8°C
ASTM D-97	±3°C

Results and discussion

Preparation of nanolubricants

One of the most effective factors of the nanofluid properties is the rate of dispersion and stability of nanoparticles inside the base fluid. When dispersion of particles inside the base fluid is not good, it is possible that agglomeration and precipitation of nanoparticles occur; in this case, macroparticles, like inclusions, develop which cause damage to frictional surfaces and also obstruct the lubricant vents. In the present research, to disperse nanoparticles inside the base oil, we used three mechanical methods including bath and probe ultrasonic and planetary ball mill (Table 2) methods. To achieve the best and the most stable state, a 0.1 wt.% sample of oil/CuO has been made using each of the three mentioned methods. All of the samples were maintained inside the completely transparent glassy containers in a completely stagnant condition for about 720 h for the purpose of evaluating their stability conditions. In this period of time, the stability condition of all the samples were periodically and visually inspected and recorded. Nanoparticles in each of the three samples had precipitated a considerable amount, although the rate of precipitation in the sample which was made by the ball mill method was very less than those of the two other samples. It seems that due to the high viscosity of base oil and also the agglomerated state of nanoparticles, for opening and dispersing nanoparticles inside the base oil, we need a great amount of energy to supply in the ball mill method at a greater rate with respect to the two ultrasonic methods.

Viscosity

The rate of oil resistance against flowing is called viscosity, which is one of the most important factors for selecting suitable oil for an apparatus. Because of the extra importance of viscosity for a lubricant, in the present research, we have focused our attention on surveying the produced changes in the engine oil's viscosity which is the result of adding CuO nanoparticles.

For this purpose, viscosity of the engine oil which did not contain nanoparticles considered as base fluid and also viscosity of the lubricants which contain CuO nanoparticles at three concentrations 0.1, 0.2, and 0.5

wt.% and also at two temperatures 40°C and 100°C were measured. The obtained results are shown in Figure 2. As it can be seen, the viscosity of nanolubricants at each of the two mentioned temperatures had increased by increasing the concentration of nanoparticles, although the rate of changes in viscosity at lower concentrations is much smaller than that at higher concentrations. The highest amount of increase in viscosity with respect to the base fluid is 5.7%, which is related to the nanolubricant with 0.5 wt.% concentration and at 40°C temperature. The interesting point related to the viscosity of nanolubricants with 0.1 wt.% concentration is that in each of the two mentioned temperatures (40°C and 100°C), the viscosity of the oil which did not contain CuO nanoparticles had a very little amount of decrease. When nanoparticles are added to the oil, they are placed between the oil layers and lead to ease of fluid layer movement on each other. As a result, viscosity will decrease slightly. As concentration increases, nanoparticles agglomerate and create larger and asymmetric particles, which prevent movement of oil layers on each other, so viscosity will increase.

So finally, it can be concluded that the viscosity of SAE 20W50 engine oil which contains CuO nanoparticles is a function of concentration of nanoparticles and at lower concentrations, it had no appreciable change with respect to the viscosity of the base oil.

Thermal conductivity

The results related to measuring the thermal conductivity coefficient of the base lubricant and the lubricant which contains CuO nanoparticles are shown in Figure 3. As it can be seen, the thermal conductivity of the engine oil which contains CuO nanoparticles had increased with respect to the base oil, although the rate of increase is only 3%. We must notice that in the case of different nanofluids, various parameters are effective in the rate of produced changes and also in their properties, including the kind of base fluid and kind of nanoparticles suspended inside the base fluid.

Flash point and pour point

The trend of changes of flash point as a function of CuO nanoparticle concentration is shown in Figure 4a. Flash point is the lowest temperature at which the oil's vapor in contact with air and as exposed to an ignition takes fire at a moment and then rapidly extinguishes. It can be seen that adding CuO nanoparticles to the base oil causes an increase in the flash point of the base oil. It can be concluded that the increase of thermal conductivity through adding of nanoparticles is attributed to the increase of oil resistance against ignition. Also, flash point has a direct relation with concentration of nanoparticles, although this relation is not linear and the intensity changes in lower concentrations are more than the changes in higher concentrations. The rate of increase in flash point of the nanofluid at 0.1 wt.% concentration with respect to the base fluid is 7.5%, and the highest amount of increase is related to the 0.5 wt.% sample, which is 13%.

The highest rate of wear in an engine is on the first moment the engine starts to work, which is produced because sufficient oil does not reach to parts, and to avoid this problem and reduce its effect, it is required that the oil be pumpable and sufficiently be flowable to easily, and with high speed, reach all parts of the engine. This property of oil is evaluated with a parameter called pour point. In fact, the oil's pour point is the boundary point of temperature in which the fluid cannot flow either. Because of the importance of this subject in the present research, the produced changes in the rate of pour point of base oil under the effect of adding CuO nanoparticles at different concentrations were studied. The trend of changes of pour point as a function of CuO nanoparticle concentration is shown in Figure 4b. As it is observed, the amount of nanolubricant pour

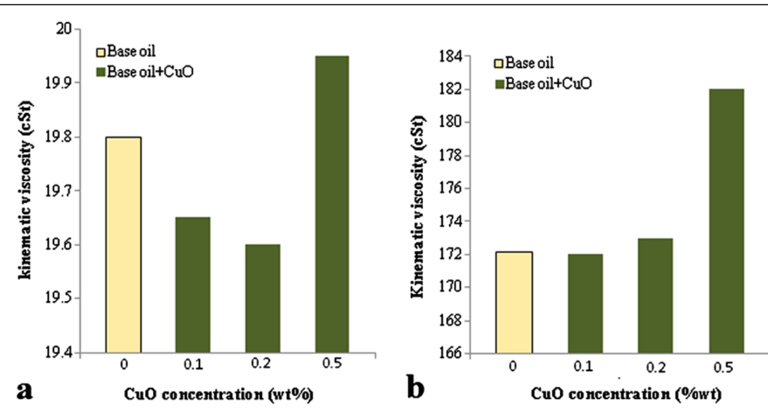

Figure 2 Kinematic viscosity of lubricants at 100°C (a) and at 40°C (b).

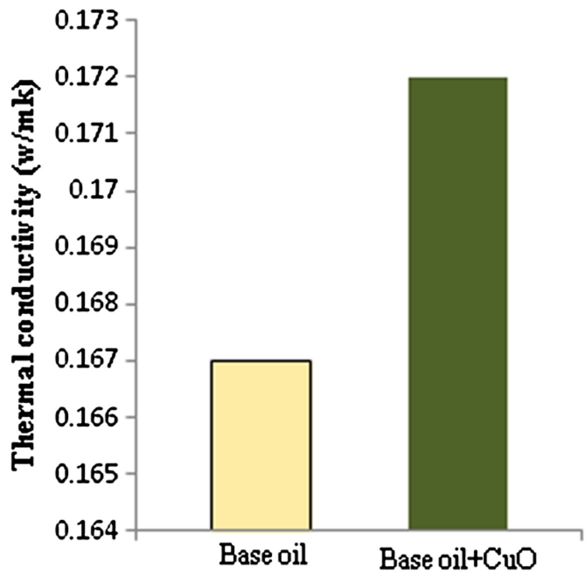

Figure 3 Thermal conductivity of nanolubricant and base lubricant.

point is seriously a function of the concentration of CuO nanoparticles such that in 0.1 and 0.5 wt.% concentrations, the pour point has decreased, but in the 0.2 wt.% concentration, there was 3.7% improvement with respect to the base oil.

Experimental

For synthesis of CuO nanoparticles, at first, Cu $(CH_3COO)_2{\cdot}2H_2O$, CH_3COOH, and solid NaOH are supplied. In our typical procedure, 600 ml of 0.2 M copper acetate aqueous solutions is mixed with 2 ml glacial acetic acid in a round-bottomed flask. Under vigorous stirring, 0.16 g of solid NaOH (pellets) is added rapidly to the boiling solution at 100°C, until the pH value of the mixture reached 6 to 7. At this stage, the color of the solutions changes from blue to black, and a black precipitate is produced simultaneously. After cooling to room temperature, the precipitate is centrifuged, washed twice with triply distilled water, ethanol, and acetone, and finally dried at room temperature.

The nanolubricants used in this study were produced by the following procedure. For example, for 0.1 wt.% sample, at first, 0.025 g of CuO nanoparticles was mixed with 25 g base oil inside the cup of the planetary ball mill, and then the ball mill worked based on the condition in Table 2.

Conclusions

Dispersing nanoparticles inside engine oil, due to the base oil's high viscosity, is a very difficult work. Upon the experiments which have been done in this research, using planetary ball mill for dispersing copper oxide nanoparticles inside the base fluid is the most suitable method because it supplies high energy preventing their agglomeration and precipitation. With increase in the concentration of nanoadditives, some of the properties of engine oil improved, but it must be noticed that an increase in concentration causes a reduction in lubricating properties of engine oil due to agglomeration and precipitation of nanoparticles and as a result causes damage to frictional surfaces. So determining the appropriate concentration to achieve better properties is a very important issue. In the present research, properties of CuO/oil nanofluids at three different concentrations were evaluated. Flash point and viscosity of engine oil had a direct relation with the concentration of nanoparticles. Thermal conductivity and flash point increased 3% and 7.5% in 0.1 wt.% concentration, respectively. The amount of pour point only at 0.2 wt.% concentration had 3.7% improvement with respect to the base fluid but decreased about 7.4% in other concentrations. Based on obtained results, it seems that the nanolubricant with 0.2 wt.% concentration is the best sample for CuO/oil because in this sample pour point and flash point are improved and viscosity has not changed much.

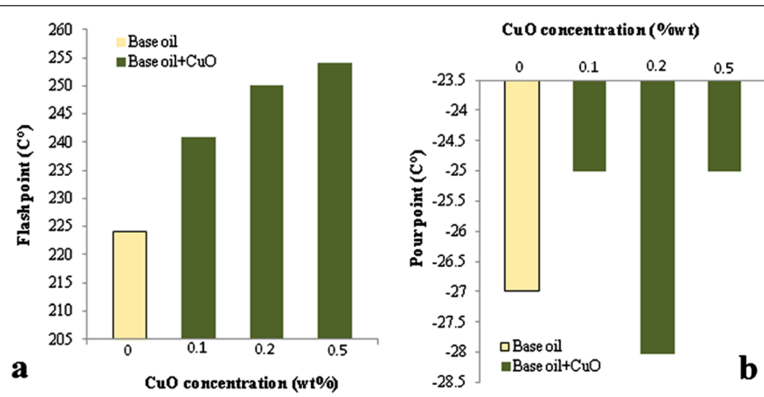

Figure 4 Flash point (a) and pour point (b) of nanolubricants.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
EE carried out all the stages of preparation and property measurement of nanolubricants. AR and MA carried out all the stages of CuO nanoparticle synthesis and analyzing them. HA and SSM participated in the interpretation of results, drafted the manuscript, and provided financial support. All authors read and approved the final manuscript.

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