The effect of SiO$_2$ nanoparticles addition on lubrication properties of 10W-40 engine oil.

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Abstract. Proper lubrication of mechanical parts in the car engines shall minimize the wear of friction pair and thus to ensure long lifetime. Another goal of the lubrication is to decrease coefficient of friction and thereby reduce energy losses. Many publications are devoted to nanoparticle addition into simple oil (e.g. paraffin) but there is only limited attention to more complex lubricants as synthetic oils. In addition, there is paid very little attention to the stability of resulting suspensions. Present paper deals with the effect of different ways of SiO$_2$ NPs addition into the advanced synthetic oil on the wear ratio of friction pair using ball-on-disc tribological test.

1. Introduction
Nowadays, a lot of people has a car, motor bike or any other vehicle. It is necessary to regularly change the motor oil to keep the engine going properly. The change is time and money consuming. These reasons are strong arguments for intensive research in the fields of oil nanoaditives.

Silica dioxide nanoparticles are widely used in various research, such as material engineering [1], medicine [2] etc. For our research, silica nanoparticles were chosen as appropriate nanoparticles due to their availability and low price on the market, very good potential of creation stable suspension and homogenous size.

The shape of the chosen nanoparticles was also important. Globular shape silica nanoparticles may lower the friction and wear due to “ball bearing” principle [4].

For ensuring the suspension stability, part of authors are putting they effort to functionalization of nanoparticles [5].

The aim of presented study is to figure out the effective method for dispergation of nanoparticles in the real, easily available motor oil with solid properties, not only paraffin [6] or any other lubricants such as organic oils [7], which cannot be used in the real vehicle. The last studied step was to evaluate the effect of used SiO$_2$ nanoparticles to the tribological properties of synthetic motor oil using ball-on-disk method.
2. Experiment

2.1. Tested oil.
Castrol GTX Ultraclean was chosen as commonly used oil, with solid tribological properties. This motor oil, with standard specification 10W-40 perfectly withstand condition of central European weather and effectively protects the engine itself.

2.2. Nanoparticles addition.
As it was mentioned previously, globular shaped silica dioxide nanoparticles, with average diameter of 20 nm were chosen as potentially suitable nanoadditives. Based on studied literature [3] and authors of previous experiences, the right amount of added nanosilica was chosen. The optimal amount of additive is an important part of whole experiment. The lack of additive cause less tribological properties differentiation. On the other side, the surplus of additive cause deterioration of tribological properties. With all of this on mind, 0.2 weight % was chosen as an ideal amount. This exact amount needs to be dispergated to establish stabile suspension.

2.3. Nanoparticle dispergation.
The common problem with addition of nanoparticles to the fluids is their clustering, which directly lowers the suspension stability. This is nature behaviour of nanoparticles. From the view of energy, it is very beneficial for the particles to create clusters, instead of staying separate and having bigger active surface.
In this paper, 3 different approaches in nanoparticle dispergation and are presented. To be concrete – usage of eccentric blender, ultrasonic waves and high energy ultrasonic pulses. All oil suspensions were treated for 20 minutes. Firstly, both methods using ultrasonic waves were tested on pure oil to be sure that the dispergation method itself does not negatively affect the tribological properties. Also, chemical functionalization of the surface of the silica nanoparticles was studied. Firstly, pH of base oil was measured for preventing inappropriate choice of chemical treatment. With slightly acidic pH, APTES ((3-aminopropyl) triethoxysilane) was chosen. Even functionalized nanoparticles were dispergated with eccentric blender.
After evaluating the tribological grooves, successful methods were used for testing the nanoadditive.

2.4. Measuring of tribological properties – tribometer and confocal microscope.
After homogenization and dispergation of the nanoadditive, next step naturally was to evaluate the effect of nanosilica on the tribological properties of the oil. For the measurement, ball-on-disc tribometer was used. Al₂O₃ was chosen as ball and chrome-manganic steel ČSN 14 220 as a disc. In the measuring bath, 70 ml oil with nanoadditive was introduced and heated to the temperature of 90 °C, which was chosen as simulation of real temperature in the engine. On the steel disk, path of 500 m on diameter of 9 mm was measured. The whole measurement took 3 hours.
After cooling to the room temperature, steel disk was cleaned by ethylalcohol and introduced to the confocal microscope to collect profile data of the groove.

3. Results and discussion

3.1. Measuring of tribological groove.
Software Gwyddion was successfully used for the groove visualisation and measuring of desired width and depth. The groove 2D model is clearly visible on Fig. 1. The software is also capable of 3D visualisation (Fig. 2) for detailed study of the groove.
Groove width and depth were measured on the mentioned 2D model (Fig. 1) as critical points in evaluation of silica nanoparticles impact.
The summarization of tribological measurement is in Tab. 1. First measurement (1 Pure oil) is reference measurement to determine tribological properties of pure oil. Second measurement (2 Pure oil high energy ultrasonic) was evaluate as inconvenient. With a high probability, the serious degradation of base oil was caused by high energy ultrasound waves. According to this measurement, the high energy pulses were no longer used in the study. As last tested method on pure oil, ultrasonic from ultrasonic cleaner remain (3 Pure oil ultrasonic). This measurement proved that no negative impact occurs after using standard ultrasonic. The impact on eccentric blender was not deeply studied due to the simplicity of mixing and no impact to the oil properties.

Addition of silica nanoparticles, which were dispergated using ultrasonic (4 SiO2 Ultrasonic) brought improvement in the width and depth of the groove. The improvement of 12,7 % seems to be promising for further research.

Measurement number 5 (5 SiO2 eccentric blender) was evaluated as most satisfying. The improvement of 13,8 % in groove width and 32,9 % in groove depth is more than promising result.
Long term ultrasonic treatment was tested to make sure even several hours of exposition does not cause the degradation of base oil. According to the results, also the long term exposition has nearly similar effect as the usage of ultrasonic high energy pulses.

The functionalized nanoparticles with APTES created whey more stable suspension and also brought slightly better results than usage of simple blender.

| Table 1. Overview of tribological measurement. |
|-----------------------------------------------|
| Groove width [µm] | Groove depth [µm] | Width difference [%] | Depth difference [%] |
|-------------------|------------------|----------------------|----------------------|
| 1 Pure oil        | 281              | 1.94                 | -                    |
| 2 Pure oil high energy ultrasonic            | 290              | 2.03                 | -3.1                 |
| 3 Pure oil ultrasonic                           | 265              | 1.83                 | 6                    |
| 4 SiO₂ Ultrasonic                               | 264              | 1.72                 | 6.4                  |
| 5 SiO₂ Eccentric blender                        | 247              | 1.46                 | 13.8                 |
| 6 SiO₂ Ultrasonic 3 hours                      | 286              | 2.09                 | -1.7                 |
| 7 SiO₂ APTES                                      | 246              | 1.45                 | 14.2                 |

![Figure 3. Graph of resulting tribological measurements.](image)

### 3.2. Discussion

With the grooving pressure for industry to be more and more ecological, the addition of nanoparticles to the motor oil to prolong the efficient time of usage and lower the wear of lubricated parts seems to be potentially good way to keep suitable industry development.

According to the results of our research, functionalization seems to be the most sufficient method for the creating stabile suspension and for improvement of tribological properties.

But, even the suspension is more stable, after several days, the nanoparticles are also sedimented and the price and time consumed of the chemical process are strong arguments to use the eccentric blender.
Eccentric blender has also convincing results to the tribological properties, but the price for the disperserion process is minimal comparing to the chemical functionalization. Also, thinking of potential industrial usage, the technology of eccentric blender is well known and for reasonable price. To sum up, the problems of sedimentation and clustering are still the most challenging problems in recent studies. It is necessary to put all effort to solving this problem and prepare stable suspension for wide common usage.

In this state, the oil with additive may be used in non-stopping processes, where the particles have no chance to sediment due to never ending flow of the oil, such as gearboxes in wind power plans or 24 hours production in the industry.

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