Experimental Investigation of Tribological Properties Using Nanoparticles as Modifiers in Lubricating Oil

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Abstract - *Nanoparticles can be used as an additive in the engine oil to improve its tribological properties to reduce wear and friction of the engine. In this research molybdenum disulphide (MoS2) and copper oxide (CuO) nanoparticles are added to engine oil SAE20W50 and tribological properties are investigated. Samples were prepared of varying percentage of CuO and MoS2 nanoparticles in engine oil (0.25, 0.5 and 1 wt. %). The friction and wear tests were performed on DUCOM's four ball tribotester and the tests were performed with varying concentration of nanoparticles in engine oil. Also viscosity tests were performed on Redwood viscometer for different samples at three different temperatures. The experimental observations show that MoS2, CuO nanoparticles added in engine oil exhibits good friction reduction and anti-wear properties and also decreased the coefficient of friction as compared with standard engine oil without MoS2, CuO nanoparticles. This tribological behavior is closely related to the deposition of nanoparticles on the rubbing surfaces*

Key Words: **MoS_2, CuO nanoparticles, tribological properties, engine oil, friction coefficient, wear**

1. INTRODUCTION

Nowadays nanoscience is one of the most expansively developing spheres of world's science and its achievements can be applied in different areas of science and technology. Nanomaterials as an example which are in the form of so called nanostructures (nanotubes, nanowires, Nano powders and others) which are widely used in many human activity fields- from cancer treatment to engineered textiles or energy storage to rocket explosives and propellant . In upcoming decades various new fields of nanostructures application will arise. One of them seems to be the unexplored area of nanostructures use as additives modifying properties (especially tribological) of lubricating or cutting oils.

Nanotechnology is regarded as the most revolutionary technology of the 21st century. It can be used in many fields of material science into a new era. In recent years numerous investigations have been carried out on the tribological properties of lubricants with different nanoparticles added in it. A number of papers from different authors all over the world have concluded that it is significantly effective to add nanoparticles to lubricant for reducing wear and friction. Among those that were added into oils, MoS2 nanoparticles have received much attention and exhibited excellent applications for their good friction reduction and wear resistance properties. The interfacial conditions which affect the reduction of wear are geometry, normal load, sliding speed, relative surface motion, surface roughness, vibration and lubrication. In addition, anti- wear properties, load-carrying capacities and friction reduction are mainly controlled by the chemical additives in lubricating fluid under boundary lubrication conditions. As the addition of a dispersing agent or the use of a surface modification preparation technique stabilizes the nanoparticles, inorganic nanoparticles have received considerable attention in the lubrication field. Nanoparticles have received considerable attention because of their special physical and chemical properties. The preparation of organic–inorganic complex nanoparticles was causing more interest in science and industry. However, few of them were used and studied as water base lubrication additives. In recent years, with the development of nanomaterial, many scientific researchers added nanoparticles into lubricating oils to improve extreme pressure, anti-wear, friction reducing properties, the efficiency and service life of machinery. The application of advanced nanomaterials has played an active role in improving and reforming traditional lubrication technology.

The anti-wear mechanism of nanoparticles when they are used as additives in lubricants can be explained in three different ways: nanoparticles may be melted and welded on the rubbing surface, reacted with the specimen to form a protective layer, or tribo-sintered on the surface. However, some authors state that nanoparticles can also act as small bearings on the rubbing surfaces. Nanoparticles penetrate into lubricated EHD contacts to form a boundary film via mechanical entrapment influencing friction and wear. These nanoparticles are entrained into sliding contacts only when the film thickness is smaller than the particle size contributing to the film thickness. The above mentioned anti-wear mechanisms of the nanoparticles take place only under mixed and boundary lubrication. Results show that nanoparticles can improve the tribological properties of the base oil, displaying good friction and wear reduction characteristics even at concentrations below 1 wt%. However, they did not compare the tribological behavior of coated nanoparticles used as lubricant additives with the non-coated ones.

2. PROBLEM STATEMENT

The conventional lubricants used for various mechanical systems consist of different types of conventional additives. The additives help to improve the lubricating and anti-wear properties of the lubricant. But these conventional additives have certain limitations at heavy loads. They are not able to maintain their original properties and thus show poor lubricating and anti-wear properties at these heavy loads. So there should be development in the additives so as to increase the working range of the lubricant by using MoS2 and CuO nanoparticles individually and by blending them at various concentration of nanoparticles.

2.1 Objectives

- To study the effect of blending of two types of nanoparticle additives on tribological properties of lubricating oil as anti-wear and EP properties.
- To study the effect of various concentrations (wt %) of nanoparticle additives on the tribological properties of lubricating oils.
- To study the effect of nanoparticle additives on viscosity, flash and fire point of oil.
- To reduce the wear and friction of engine parts.

2.2 Methodology

- Selection of suitable nanoparticles depending upon size, shape, structure and function.
- Selection of a lubricant oil regarding its particular application
- Preparation of material to be tested i.e., preparation of nanoparticles for their specific concentration and quantity of lubricant to be tested.
- Carrying out different types of tests as per standards i.e., wear and extreme pressure test, flash and fire point test and lastly viscosity test.
- Evaluation of expected results and experimental results.

3. MEHODOLOGY

1. Wear rate tests(ASTM 4172)
2. Viscosity tests (ASTM D445)
3. Flash and fire point tests (ASTM D92)

4. MATERIALS USED

4.1 Materials

The SAE 20W50 engine oil was used as the base oil. The pure lubricants contains some additives for friction reduction and anti-wear, but the base oil purchased does not. Pure lubricants are manufacturers of industrial lubricant, automobile oil and greases. The properties of base oil are given in table no.1.

Table -1: Properties of Base oil SAE 20W50

Properties	Range
Appearance	Brown
Density at 15°C	879 kg/m^3
Viscosity at 40°C	156 cSt
Viscosity at 100°C	17.7 cSt
Viscosity Index	103
Flash Point (°C)	210
Fire Point (°C)	241

MoS2 and CuO nanoparticles, as shown in Figure 1 and 2 are purchased from Mahavir Sales Corp, Ahmednagar.

Fig -1: Copper oxide (CuO) in form of nano powder

Fig -2: Molybdenum disulphide (MoS_2) in form of nano powder

4.2 Preparation of Nano-oil

The rate of dispersion and stability of nanoparticles inside the base fluid are the most effective factors of the Nano fluid. When dispersion of particles inside the base fluid is not good, it is possible that agglomeration and precipitation of nanoparticles occur; which may cause damage of the frictional surfaces. We used oleic acid as surface modifier and by preparing lubricant samples in concentrations of 0.25 wt%, 0.5 wt% and 1wt% using a magnetic stirrer. The bibliographic research shows the concentration of nanoparticles in the range of 0.2-1 wt% gives best results.

Table -2: Properties of the materials MoS_2 and CuO

Nanoparticles	Properties
MoS2	Appearance: shiny dark gray Purity: 99.9 % (metal basis) Morphology: spherical True density: 5.06 g/cm3 Crystallographic Structure: cubic Making Method: Laser evaporating
CuO	Appearance: brown black powder Purity: 99% (metal basis) APS: 25-55 nm SSA: 13.98 m^2/g Morphology: nearly spherical Bulk density: 0.79 g/cm^3 True density: 6.4 g/m^3

5. EXPERIMENTATION

Table -3: Design of experiment details

Sr. No	Lubricant	Additive	Conc. of additive (g/100ml oil)	Wear Test
1	SAE20W50	-	-	W1
2	SAE 20W50	MoS2	0.25	W2
3	SAE 20W50	CuO	0.25	W3
4	SAE 20W50	MoS2+CuO	0.25+0.25	W4
5	SAE 20W50	MoS2	0.5	W5
6	SAE 20W50	CuO	0.5	W6
7	SAE 20W50	MoS2+CuO	0.5+0.5	W7
8	SAE 20W50	MoS2	1	W8
9	SAE 20W50	CuO	1	W9
10	SAE 20W50	MoS2+CuO	1+1	W10

As mentioned in above table different samples as per additives added into them are denoted as W1 to W10 for wear tests. In similar manner, samples for viscosity tests are denoted as V1 to V10. Also, samples for flash and fire point's tests are denoted as F1 and F10.

6. RESULTS OF TRIBOLOGICAL TESTS

6.1 Results of Wear Tests

The wear preventive characteristic of base oil (SAE20W50) is tested with 2 different anti-wear additives i.e. molybdenum sulphide (MoS2) & copper oxide (CuO). First of all, in this research, we have done wear testing for base oil i.e. SAE20W50 oil and then base oil with additives (MoS2 and CuO nanoparticles) at different concentration. So, the wear test results shows the graphs of frictional torque (Nm) Vs time (Sec) for various oil samples. These graphs are acquired from Winducom 2010 software. The graphs of frictional torque Vs time for various samples as shown below. The graphs also show the coefficient of friction.

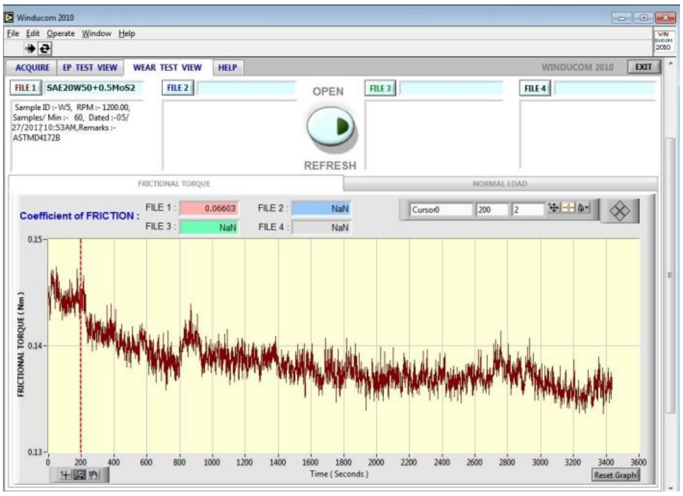
- Coefficient of friction(COF)

For these experiments, the frictional torque from a four ball tribo tester was recorded. From the frictional torque values, the coefficients of friction of the lubricants were determined by using Equation 1.

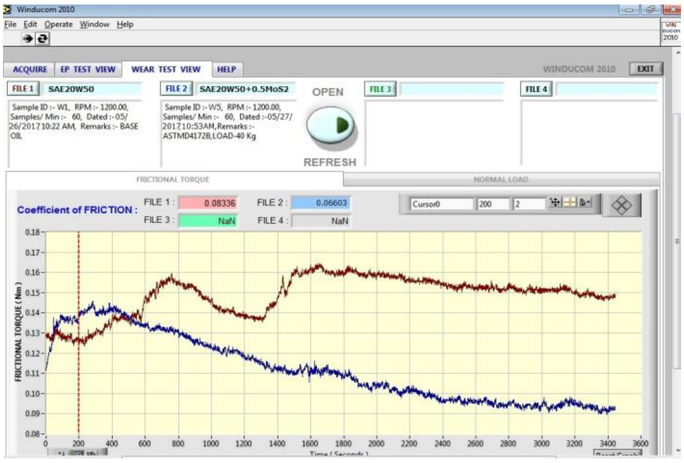
$$\mu = T\sqrt{6}/3Wr \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where μ is the coefficient of friction, T is the frictional torque in kg/mm, W the applied load in kg and r the distance from the centre of the contact surface on the lower balls to the axis of rotation, which is 3.67 mm.

- Graph of frictional torque vs time and scar images for test sample W5



Graph -1: of frictional torque (Nm) Vs time (sec) for sample W5 (Base oil +0.5%MoS2)



Graph -2: Comparison graph between sample W5 (Base oil +0.5%MoS2) and W1 (base oil)

(a) Ball One (b) Ball Two (c) Ball Three

Figure -3: Scar images for sample W5 (Base oil +0.5%MoS2)

All graphs and images show coefficients of friction and the wear scar diameter for the tested oils with the help four ball oil tester software and image acquisition system. The image acquisition and magnification are done with the help of Winducom 2010 software.

Table -4: Results of wear Test

Sample Name	Ball	Wear scar dia.	Average diameter(μ)	Coefficient of friction
W1	Ball 1	98	96	0.08360
	Ball 2	96		
	Ball 3	94		
W2	Ball 1	81	82	0.06739
	Ball 2	84		
	Ball 3	80		
W3	Ball 1	82	85	0.06774
	Ball 2	86		
	Ball 3	88		
W4	Ball 1	75	84	0.08149
	Ball 2	92		
	Ball 3	86		
W5	Ball 1	76	70	0.06603
	Ball 2	77		
	Ball 3	56		
W6	Ball 1	104	92	0.06739
	Ball 2	73		
	Ball 3	98		
W7	Ball 1	75	86	0.07678
	Ball 2	94		
	Ball 3	89		
W8	Ball 1	78	79	0.07445
	Ball 2	82		
	Ball 3	77		
W9	Ball 1	124	111	0.08774
	Ball 2	90		
	Ball 3	118		
W10	Ball 1	89	88	0.07965
	Ball 2	87		
	Ball 3	88		

From the above result table and graph, it is clear that coefficient of friction of base oil with nanoparticles additives is lower than that of base oil. It is found that the highest value of the coefficient of friction is given for the test lubricant W7 which is base oil+1%CuO. Its coefficient of friction value is 0.08774. However, the lowest value of the coefficient of friction is for the test lubricant W5 (base oil +0.5%MoS2) which is 0.06603. The coefficient of friction of test lubricant samples W2, W3, W5, W6, W7, W8 and W10 is lower than base oil sample W1. The samples W4 and W9 shows more coefficient of friction as compare to base oil sample W1.

6.2 Results of Viscosity Tests

Sample	Time required to collect oil			Kinematic viscosity (cSt)		
	50^0 C	60^0 C	70^0 C	50^0 C	60^0 C	70^0 C
V1	255	137	132	55.39	28.82	27.67
V2	257	140	138	55.84	29.51	29.05
V3	259	156	142	56.28	33.16	29.97
V4	260	165	148	56.50	35.20	31.34
V5	258	222	164	56.06	41.0	34.98
V6	260	174	155	56.50	37.24	32.93
V7	265	226	169	57.62	48.92	36.11
V8	271	185	161	58.95	39.72	34.30
V9	270	180	158	58.73	38.60	33.62
V10	298	235	177	64.95	50.93	37.92

The samples V1 to V10 are the various samples for testing having various percentages of nanoparticles of molybdenum disulphide and copper oxide and blending of both nanoparticles in the SAE20W50 lubricating oil.

Experimental results shows the viscosity of oil at 50°C, 60° C and 70° C are increased as compare to the sample which does not contains additives. The graph and result table shows that viscosity of engine oil had directly relation with the concentration of nanoparticles. For sample V10 (Base oil +1%MoS2+1%CuO) shows highest viscosity at various temperature.

7. CONCLUSIONS

In the present research, properties of lubricating oil (SAE20W50) is evaluated by addition of MoS2 and CuO nano-particle at three different concentrations.

From the results of this present investigation and the discussion presented in the earlier chapters, the following conclusions are drawn. The following conclusions are obtained from experimental results.

1. Addition of nanoparticle in oil increases the viscosity of oil. And graph shows that sample V10 (Base oil+1%MoS2+1%CuO) shows highest viscosity at various temperatures.
2. From the wear test result the coefficient of friction is decreased from 0.08360 to 0.06603.However, from the results wear scar diameter tests it is clear that almost all the samples shows less wear scar diameter as compared to base oil. The smallest wear scar diameter is found on the ball lubricated with W5 sample (base oil+0.5%MoS2).
3. This shows that the nanoparticles has the potential of acting as a performance enhancer (additive) in the lubricant. So to achieve better properties determining the appropriate concentration is a very important.

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