Comparison of Tribological behavior of SAE 5W30 mineral oil with addition of nickel based nanoparticle additives

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Abstract - *A lubricant is a substance that reduces friction and wear by providing a protective film between two moving surfaces. Good lubricants possess the properties such as high viscosity index,high flash and fire point, high load carrying capacity, excellent coefficient of friction, good anti-wear capability, low emission into the environment and to enable withstanding high temperatures. Nanoparticles can be used as an additive in the engine oil to improve its lubrication properties to reduce wear and friction of the engine. The purpose of the present research is to add Nickel-carbon coated (NiC) and Nickel oxide (NiO) nanoparticles to SAE 5W30 mineral oil and evaluate the produced changes in some of its properties. Samples were prepared of varying percentage (0.5, 1 and 2 wt %) of nanoparticles in lubricating oil. The antiwear test was conducted using four ball tribotester according to standard ASTM D 4172b.Viscosity and Flash and Fire point test was evaluated using redwood viscometer and open cup tester apparatus according to ASTM standard respectively.*

The results shows that both nanoparticles as additives in lubricating oil and their combinations improves the tribological properties of the lubricant. 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.

***Key Words*:**
Additives, Lubricant, Nanoparticles, Four ball tester, Wear scar diameter etc

1.INTRODUCTION

Nanotechnology is regarded as the most revolutionary technology of the 21st century. It can be used in many fields and 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 large number of papers have reported that the addition of nanoparticles to lubricant is effective in reducing wear and friction .Among those that were added into oils, Ni nanoparticles have received much attention and exhibited excellent applications for their good friction reduction and wear resistance properties . The reduction of wear depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding speed, surface roughness, lubrication, and vibration. 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. Since stabilization of nanoparticles has been resolved by the addition of a dispersing agent or the use of a surface modification preparation technique, inorganic nanoparticles have received considerable attention in the lubrication field. Nanoparticles have received considerable attention because of their special physical and chemical

2.LITERATURE REVIEW

The purpose of this chapter is to present a comprehensive literature review summarizing the previous published work relevant to research work. Numerous nanoparticles have recently been investigated for use as oil additives.

Binfa Bongfa et. al. (2015) studied Comparison of lubricant properties of castor oil and commercial engine oil. The tribological performance of crude Nigeria-based castor oil has been investigated and compared with that of a foreign, 20W-50 high quality crankcase oil, to see its suitability as base oil for lubricating oils in indigenous vehicle and power plants engines. The results showed that unrefined castor oil has superior friction reduction and load bearing capability in an unformulated form than the commercial oil hence can be a good alternative base stock for crankcase oils [1]

Shubrajit Bhaumik et.al. (2014) investigated the antiwear and extreme pressure properties of multiwall carbon nanotube based mineral oil. The samples were tested for their antiwear and load bearing capacity according to ASTM G99 and ASTM D-2783 standards. The wear test results show a decrease wear in case of multiwall nanotube based mineral oil as compared with pure mineral oil. [2]

A. S. Kalhapure et.al. (2015) studied performance evaluation of tribological properties of cotton seed oil for multi-cylinder engine. The purpose of this work is to evaluate the anti-wear characteristics of cottonseed oil and to check the suitability of cottonseed oil as a lubricant for multi-cylinder engine. Four ball testing machine is used for anti-wear testing as per ASTM D 4172. The wear preventive characteristic of cottonseed oil is obtained by measuring wear scar diameter. Only wear preventive characteristic of cottonseed oil is considered in this research work. Though coefficient of friction for cottonseed oil is lower compared to commercial lubricants, the wear scar diameter is larger. Hence cotton seed oil cannot be used as a lubricant in the unmodified form. [3]

R. Chou et.al. (2010) examined the influence of addition of 20 nm diameter nickel nanoparticles on the tribological performance of synthetic oil (polyalphaolefin, PAO6). A tribometer used for testing at medium loads and a four-ball machine (ASTM D2783) were used in this research. Wear surfaces were analyzed by SEM and EDS. The study leads to the conclusion that the addition of nickel nanoparticles to PAO6 results in a reduce in friction and wear and an increase in the load carrying capacity of PAO6 oil. [4]

Y.Y. Wu et.al. (2007) study examined the tribological properties of two lubricating oils, API SF engine oil and Base oil, with CuO, TiO2, and Nano-Diamond nanoparticles used as additives. The friction and wear experiments were performed using a reciprocating sliding tribotester. The experimental results show that nanoparticles, particularly CuO, added to normal oils show good friction reduction and anti wear properties. [5]

The ASTM International gave the standard test method for wear preventive characteristics,viscosity and flash and fire point tests of lubricating oil.This ASTM journal gave the detailed specifications of four ball wear test machine with significance and use. Preparation of apparatus, material of the balls, test conditions, and detailed procedure are explained in this journal. [6]

Summary of Literature

- In the literature lot of papers are published on nanoparticle as a additives in lubricating oil. The nanoparticle such as Cu,CuO,Fe,Ni,TiO2,SiO2,diamond,graphite are used as additive in lubricating oil. All of them provide good friction reduction and anti-wear behaviour at optimum concentration
- The friction reduction and anti-wear behaviours are dependent on the characteristics of nano-particles such as size, shape and concentrations.
- From literature review it is clear that there is vast scope for study on nanoparticles as a additives in lubricating oil.
- Many of the researchers worked on the different mineral oil like SAE 20W40,SAE10W30,SAE20W50 and the result shows a great potential as a lubricant.so the SAE5W30 mineral oil is used for this research work.
- There is no comparative study is done on nickel based nanoparticle and in most paper nanoparticle used as additive in synthetic oil but there is scarce data in literature on mineral oil.

3) OBJECTIVES

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

4) MATERIALS & METHODS

Nanoparticles Used-

The different types of nanoparticles used in this work are as follows,

1) Nickel-Carbon Coated(NiC)
2) Nickel oxide(NiO)

Nickel (Ni) carbon coated :

- Appearance: grey and black powder
- Purity: 99% (metal basis)
- APS: 20 nm
- SSA: 30 - 50 m^2/g
- Morphology: spherical
- Bulk density: 0.10 - 0.25 g/cm^3
- Making method: Laser Evaporation

Nickel Oxide (NiO)

- Appearance: green powder
- Purity: 99.5 %
- APS: 20 nm
- SSA: 60-100m^2/g
- Morphology: nearly spherical
- True density: 6.67g/cm^3
- Bulk density: 0.7-0.8 g/cm^3
- Crystallographic Structure: cubic
- Making Method: Laser evaporating

Nomenclature:

- **APS** : Average Particle Size
- **SSA** : Specific Surface Area

Lubricant used:
The lubricant is used in this work are as follows,
➢ SAE 5W30 mineral oil:-

Specification of SAE 5W30 engine oil

- Viscosity at 40°C (cSt) : 63.2
- Viscosity at 100°C (cSt): 10.5
- Density at 15°C (kg/m3): 859
- Viscosity index :154
- Flash point (°C): 224
- Pour point (°C): −36

Material Preparation

The nanoparticles are dispersed in **SAE 5W30** engine oil. The Precision balance is use for measuring weight of oil and nanoparticle additives and magnetic stirrer is used for dispersion of nanoparticle in oil. Oleic acid is used as a surfactant in the dispersion process to prevent nanoparticle agglomeration and thus improve the dispersion stability of NiC and NiO nanoparticles

5) EXPERIMENTATION

In this project we have two different of types additives and three different concentrations in lubricating oils. We have the study of the effect of these variables on wear scar diameter. The nanoparticles are dispersed in SAE5W30 engine oil. Oleic acid is used as a surfactant in the dispersion process to prevent nanoparticle agglomeration and thus improve the dispersion stability of NiC and NiO nanoparticles.

Table No. 1 Design of experiment Details

Sr.No	Lubricant	Additive	Concentration of additive (g/100ml oil)	Wear Test
1	SAE 5W30	-	-	W1
2	SAE 5W30	NiC	0.5	W2
3	SAE 5W30	NiO	0.5	W3
4	SAE 5W30	Ni+NiC	0.25+0.25	W4
5	SAE 5W30	NiC	1.0	W5
6	SAE 5W30	NiO	1.0	W6
7	SAE 5W30	Ni+NiC	0.5+0.5	W7
8	SAE 5W30	NiC	2.0	W8
9	SAE 5W30	NiO	2.0	W9
10	SAE 5W30	Ni+NiO	1.0+1.0	W10

5.1 Samples for wear test

Table No- 2: Samples for wear test

Sr. no	Name of the sample	Wt of oil (35 ml by wt %)	% of additives	Wt of Additives(gm)
1.	W1	28.215	0	-
2.	W2	28.535	0.5	0.1426
3.	W3	28.230	0.5	0.1412
4.	W4	28.290	0.25+0.25	0.0707+0.707
5.	W5	28.543	1	0.2854
6.	W6	28.636	1	0.2863
7.	W7	28.320	0.5+0.5	0.1416+0.1416
8.	W8	28.328	2	0.5660
9.	W9	28.662	2	0.5732
10.	W10	28.532	1+1	0.2853+0.2853

Fig-1: Samples of wear test

6) Wear test

6.1 Tools Required for Accomplishment of Wear test

6.1.1 Four ball Test Rig

Experimentation is an important part of any research work. So to test the wear preventive characteristics of lubricant we have selected a standard four ball testing machine with standardized testing method i.e. American Society for Testing and Materials (ASTM). DUCOM's four ball tester TR-30 family is designed to determine wear preventive (WP), extreme pressure (EP) and shear stability behavior of lubricants. Apparatus measures the coefficient of friction, wear scar diameter and load carrying capacity of lubricating oils under standard operating conditions. The mechanical tester consists of spindle assembly, motor, ball pot assembly, loading arrangement. There is a built-in accessory storage and ball tray to hold test balls. Also the test rig includes sensors, PC based machine control, data acquisition system and display. The four ball tester uses four balls, three at the bottom and one on top. The bottom three balls are clamped firmly in a ball pot containing the lubricating oil under test. The top ball is made to rotate at the desired speed while the bottom three balls are pressed against it. The test load, duration, temperature and rotational speed are set as per the ASTM standard test schedule. A unique device "Collate Master" makes it very easy to insert and remove test ball in collate . The Ducom four ball testing machine is as shown in Fig.2

Fig-2: Ducom—TR 30 L Four Ball Test Rig

A. Specifications

Specifications of Ducom four ball tester contain the information related standard codes for the different tests, technical data and mechanical specifications.

B. Standards

Table No-3: Standard codes for the tests performed on four ball tester

Sr. No.	Title of Test	Code
1.	Wear preventive properties of lubricating fluids	ASTM D 4172
3.	Extreme pressure properties of lubricating fluids	ASTM D 2783

C. Mechanical Specifications

Table No-4: Mechanical specifications of four ball tester

Sr. No.	Part Details	Range
1.	Collect Diameter	12.7 mm
2.	Base plate height from floor	924 mm
3.	Loading Arm height from Floor	1050 mm
4.	Ball pot height from floor	1230 mm
5.	Loading Arm Length	935 mm
6.	Loading arm ratio	1:15
7.	Maximum Load	9999 N
8.	Minimum Load	60 N
9.	Dead weights	In steps of 1, 2 and 5 Kg
10.	Motor Height from floor	1580 mm
11.	Spindle speed	Min 1000 rpm Max 3000 rpm
12.	Pulley Ratio	1:1
13.	Overall sizes of the machine L×W×H	660×935×1650 mm
14.	Weight of the Machine	388 Kg
15.	Floor Size L×W	2500×1500 mm

6.1.2 Testing Balls

Testing balls are made of chrome alloy steel, made from AISI standard steel No. E-52100, with a diameter of 12.7 mm [0.5 in.]. Such balls are described in ANSI Specifications B 3.12. The extra polish finish is not described in that specification. The Rockwell C hardness shall be 64 to 66, a closer limit that is found in ANSI requirement. The balls used are shown in Fig.3

Fig.3 -Testing balls

6.1.3 Image Acquisition System

Image acquisition system is used to measure the wear scar diameters on worn lower three balls. The image acquisition and magnification are done with the help of Winducom 2014 software. The image acquisition system is as shown in Fig.4

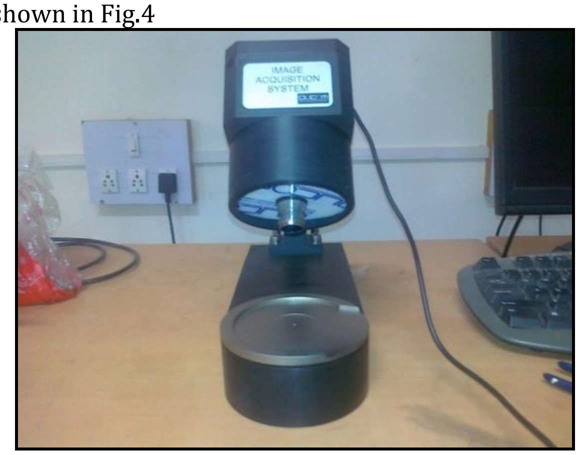


Fig.4 Image acquisition system (Ducom made)

6.2 Tribological Testing

Four-Ball tester TR-30L model is versatile equipment combining the features of both Four Ball Extreme Pressure and Four ball wear test machines. In this tester three 12.7 mm diameter steel balls are clamped together and covered with lubricant to be evaluated, a fourth ball of same dia referred to as top ball is held in a special collect inside spindle, rotated by AC motor . The top ball is rotated in contact with three fixed bearing balls, which are immersed in sample oil. Inside the ball pot the balls are held in position against each other by a clamping ring and force applied by tightening lock nut, additional provision to heat and control temperature of oil sample is also provided at bottom of ball pot. Normal load is applied on the balls by loading lever and dead weights placed on loading pan. The ball pot is supported above the loading lever on a thrust bearing & plunger and beneath plunger a load cell is fixed to loading lever to measure normal load. The frictional torque exerted on the three balls is measured.[1]

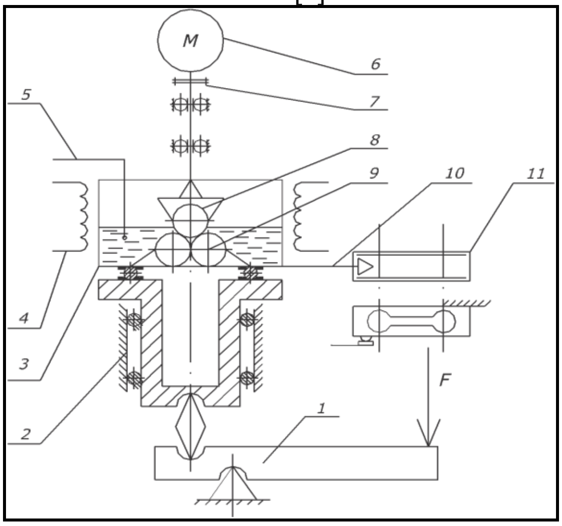


Fig-5: Schematic diagram of four-ball tester with friction torque measurement

1.	Loading lever
2.	Vertical centering bearing
3.	Oil tank
4.	Oil heater
5.	Temperature sensor
6.	Electromotor
7.	Muff
8.	Rotating ball
9.	Fixed balls
10.	Communicator of friction torque
11.	Force sensor

Fig-6: Ball pot assembly

Table No-5: Test setting (ASTM D 4172 B)

Sr.No	Parameter	WEAR TEST	
		Specification	**Condition during setting**
1	Speed	1200 rpm	1200 rpm
2	Temperature	75°C	75°C
3	Test duration test	60 min	60 min
4	Normal load	392±2N	392±2N
5	Test ball	Material: AISI standard steel no E-52100, dia 12.7mm, grade 25 EP, 64-66 HRc	Make: SKF ball of same specification

6.2.1 Procedure

The detailed procedure for measuring the wear preventive characteristics of oil is mentioned below

- ✓ First of all properly clean the testing balls, oil cup and clamping parts using acetone.
- ✓ Tighten one of the clean balls into the spindle of test machine and assemble three clean test balls in the oil cup with the help of wrench.
- ✓ Pour the oil into the test-oil cup in such way that oil cup is being completely filled without air pockets.
- ✓ Set up the four ball tester with desired speed, temperature, time and load as per the prescribed test conditions given below.

Table No-6: Test conditions

Parameters	Condition
Load	392 ± 2 N
Temperature	75 ± 2 ºC
Speed	1200 ± 60 rpm
Time	60 ± 1 min

- ✓ When all the test conditions are reached, start the drive motor which was previously set to drive the top balls.
- ✓ After the completion of test for 1 hr drive motor automatically stops and then turn off the heater, remove the test oil cup assembly.
- ✓ Last step is to measure the wear scars on the three lower balls with the help of image acquisition system and winducom software.

6.2.2 Measurement of Wear Scar by Using Image Acquisition System

The wear scars formed on the bottom three balls after the tests is measured to determine wear preventive characteristics of the test lubricant. In general, the larger the wear scar diameter, the more severe the wear. Measurement of wear scars on the lower three balls is done by following method Drain the oil from ball pot assembly and wipe the scar area with the help of tissue paper and acetone.

Leave the three balls clamped and set the assembly on a special base of an image acquisition system that has been designed for special purpose.

Measure the wear scar diameter on the major axis and minor axis and take mean value of that, as given by software.

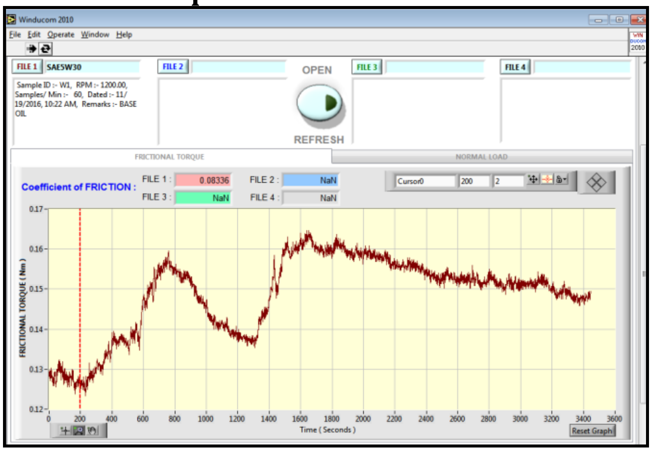
Repeat the same procedure for each ball in the ball pot.

7 Results of wear test

The wear preventive characteristic of base oil (SAE5W30) is tested with 2 different anti-wear additives i.e. Nickel-Carbon coated & nickel oxide. First of all, in this research, we have done wear testing on base oil i.e. SAE 5W30 oil and then base oil with additives (NiC and NiO 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.

7.1 Sample Graph of frictional torque vs time and scar images for test sample W1 and W3

7.1.1 Test sample W1:

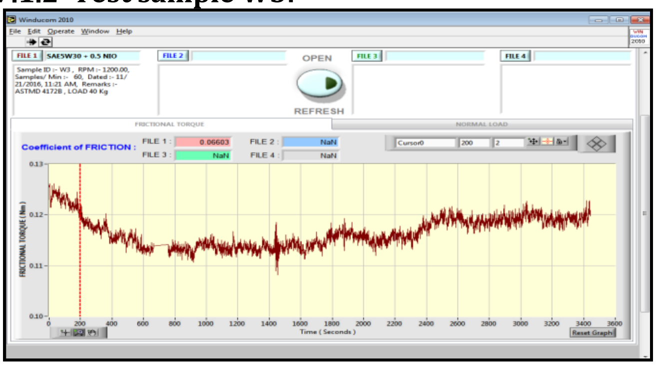


Graph-1: Graph of frictional torque (Nm) Vs time (sec) for sample W1 (SAE5W30 base oil)

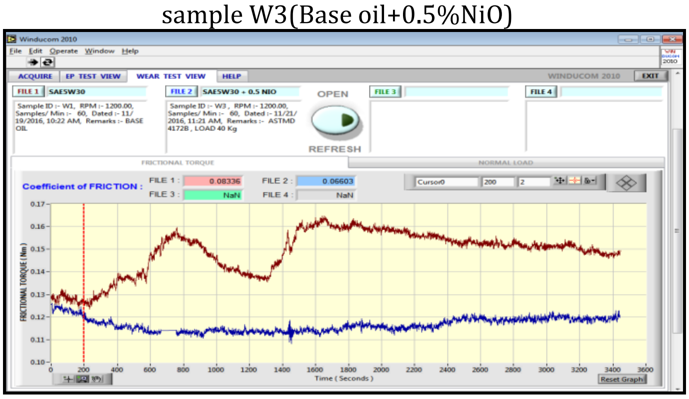
a)Ball One (b) Ball Two (c) Ball Three

Fig-7- Scar images for sample W1 (SAE 5W30 base oil)

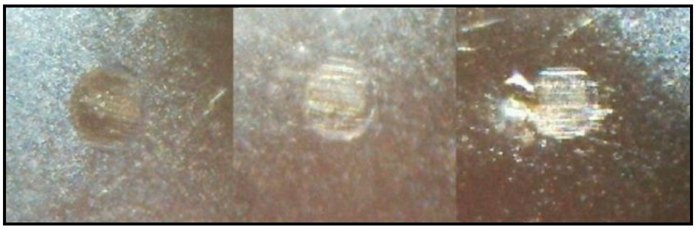
7.1.2 Test sample W3:



Graph-2: Graph of frictional torque (Nm) Vs time (sec) for sample W3(Base oil+0.5%NiO)



Graph-3: Comparison graph between sample W3(base oil+0.5%NiO) and W1 (base oil)



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

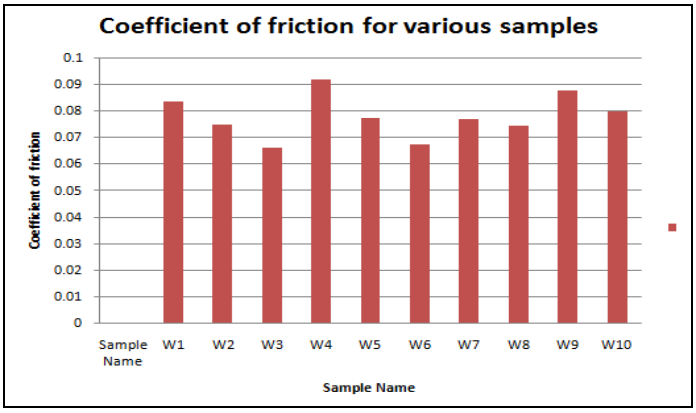
Fig-8: Scar images for sample W3 (base oil+0.5%NiO)

Above graphs and images shows 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 2014 software.

Average values of the coefficients of friction and wear scar diameters for sample W1 to W10 are as shown in table no.12.

Table No-7 : Results of wear Test

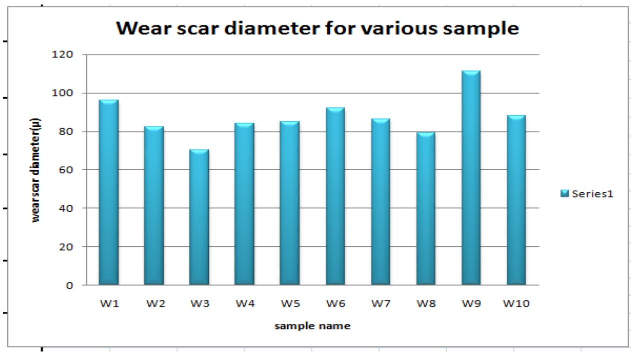
Sample Name	Ball	Wear scar diameter(μ)	Average diameter(μ)	Coefficient offriction
W1	Ball 1	98	96	0.08360
	Ball 2	96		
	Ball3	94		
W2	Ball 1	81	82	0.07467
	Ball 2	84		
	Ball 3	80		
W3	Ball 1	76	70	0.06603
	Ball 2	77		
	Ball 3	56		
W4	Ball1	75	84	0.09159
	Ball 2	92		
	Ball 3	86		
W5	Ball 1	82	85	0.07732
	Ball 2	86		
	Ball 3	88		
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		



Graph- 4: Graph of Coefficient of friction for all test samples

7.2 Coefficient of friction(COF)

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 W4 which is base oil+0.25%NiC+0.25%NiO. Its coefficient of friction value is 0.09159. However, the lowest value of the coefficient of friction is for the test lubricant W3 (base oil +0.5%NiO) 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.And the samples W4 and W9 shows more coefficient of friction as compare to base oil sample W1.



Graph-5: Graph of Wear scar diameter for all test samples

7.3 Wear scar diameter (WSD)

The results show that both nanoparticles as additives in SAE5W30 mineral oil at a various concentration have better anti-wear and antifriction properties than the pure SAE5W30 base oil. Graph shows the less wear scar diameter as compare to the sample which not contains additives.

The smallest wear scar diameter is found on the ball lubricated with W3 sample.(base oil+0.5%NiO). however, the largest wear scar diameter was found on those ball lubricated with W9(base oil+2%NiO), which is 111 micon.The wear scar diameter of the balls lubricated with test lubricant samples W2, W3, W4, W5, W6, W7, W8 and W10 is lower than base oil sample W1.

7.4 Result shows Comparison between base oil sample and best sample with additives

Sample	Flash point (^{0}C)	Fire point (^{0}C)	Viscosity(cSt)			Wear scar diameter(µ)	Coefficient of friction
			50 ^{0}C	60^0 C	70^0 C		
SAE 5W30(base oil)	224	236	55.39	28.82	27.67	96	0.08360
Base oil+0.5 %NiO	232	241	56.28	33.16	29.97	70	0.06603

Table no-8: shows results of base oil sample and the sample shows best result as compared to other sample that we have studied in experimentation.So the sample (base oil+0.5%NiO) shows good overall result.

8.CONCLUSION

In the present research, properties of lubricating oil (SAE5W30) is evaluated by addition of NiC and NiO nanao 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. 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 W3 sample.(base oil+0.5%NiO).
2. 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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