Experimental Investigation of Fluid Viscosity Effects on Free Damped Vibration

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***Abstract*—The present study includes the study of damping coefficient and kinematic viscosity of three grades of engine oil by adding two grades of viscosity index improver. Oil acts as good damping material. Four stroke engine oil SAE10W30, SAE15W40 and SAE20W50 are taken and two types of viscosity index improver (OCP) are added in the three grades of oil by varying the percentage weight by 5%, 10%, and 15% of additive. Free vibration test is carried out for all the above mentioned types of oil at different percentage weight of additives for finding the damping coefficient on Universal Vibration Testing Machine. Redwood Viscometer is used to find out the kinematic viscosity of all the above mentioned types of oil with the additives. The experimental design consist of L_9 orthogonal array involving three levels of engine oil grade and three levels of both additive concentrations. The presence of viscosity index improver has significantly improved the damping properties of engine oil. The relation between damping coefficient and kinematic viscosity is predicted by regression analysis for both the additives.**

***Index Terms*—Damping coefficient, engine oil, free vibration, viscosity, viscosity index improver, etc.**

I. Introduction

The viscosity of a fluid is resistance to gradual deformation by shear stress. An ideal fluid has no resistance to shear stress. However, a viscous liquid has substantially greater viscosity than that of water. Viscous damping is the most common used damping mechanism in vibration analysis. When mechanical system vibrate in a fluid medium such as air, gas, water and oil, the resistance offered by the fluid to the moving body causes energy to be dissipated. In this case, the amount of dissipated energy depends on many factors, such as the viscosity of the fluid, the frequency of vibration and velocity of vibrating body. Engine oil is used for lubrication of internal combustion engines. Lubricants reduce wear on moving parts. The other properties are to clean, inhibit corrosion, improve sealing, and for cooling of the engine. Friction and wear is caused due to vibration of the component. The principal of viscous damping is to convert kinetic energy due to vibration to heat. Dampers have been widely used to reduce the amplitude of vibration by absorbing or dissipating energy. Hydraulic oil used for viscous damping is also used to reduce engine wear under severe operating conditions, reduced bearing related wear, good piston deposit control, protection against rust and corrosion. We will focus on viscous damping in this project and carry out experimental investigation of damping coefficient and kinematic viscosity of different engine oil.

II. Literature Review

Meena et al[3] have studied the tribological behaviour of titanium oxide (TiO_2) nanoparticles as additives in mineral based multi-grade engine oil. The outcome is that mixing of TiO_2 in engine oil reduces the friction. It also improves the lubricating properties of engine oil along with reducing wear rate. Friction and wear are caused due to vibration of component and lack of damping. Mohd Azman Abdullah et al [4] work has been on mixing of two types of lubricants maximize wear reduction. Comparison has been made among various compositions of mixtures to analyse viscosity index, coefficient of friction and wear scar diameter. The results reveal the mixture with 30% of ATF is superior in terms of wear resistance. Pavlo Rudenko et al [5] have examined the talc as friction reducing additive. The findings indicate that ultrafine talc powder is environmentally friendly extreme pressure (EP) additive. Hidetsugu Kuroda et al [6] have determined the principles and characteristics of viscous damping devices (gyro-damper), the damping forces which are highly amplified by converting the axial movement to rotary one. Damping force and damping coefficient can be obtained by varying the screw pitch, diameter of rotor, area of rotor and viscosity of viscous material. This device is useful for large amplitude and micro-amplitude. Bryan O'Rourke et al [7] have worked on Tri-Axial Force Measurements on the Cylinder of a Motored SI Engine Operated on Lubricants of Differing Viscosity whose experimental results showed that the changes in friction characteristics occurred in floating liner engine due to changes in lubricant viscosity and temperature. Avinash A. Thakre et al [8] have worked on Improvement in Boundary Lubrication Characteristics of SAE20W40 Oil Using Aluminum Oxide Nanoparticles by designing the experiment of L_{18} orthogonal array having six levels for nanoparticles concentration and three levels for nanoparticles size, sliding speed, and normal load which shows that the lubrication properties of oil has improved due to presence of nanoparticles. N. Nunn et al [9] have studied Tribological properties of polyalphaolefin oil modified with small amount of nanocarbon additives by using block-on-ring experiments for examining tribological properties of polyalphaolefin (PAO) oil. PAO oil containing nanodiamond particles, onion-like carbon (OLC), single/multiwall carbon nanotubes (SWNT/MWNT) or nanographene platelets (NGPs) was taken for analyzing coefficient of friction (COF) and wear. Muhammad Ilman Hakimi Chua Abdullaha et al [10] have worked on Optimization of Tribological Performance of hBN/AL_2O_3 Nanoparticles as diesel engine oil (SAE 15W40) additives. The analysis of signal-to-noise (S/N) ratio and analysis of variance (ANOVA) shows that COF and wear scar diameter were reduced by several concentrations of hBN nanoparticles in diesel engine oil without nanoparticles and with Al_2O_3 nanoparticle additive.

III. Problem definition

According to the literature survey it is seen that there is no correlation determined for effect of engine oil viscosity on damping coefficient. Thus the present work is on developing the correlation between damping coefficient and kinematic viscosity.

IV. Experimental Setup Details

Design Of Experiment (DOE) by using Taguchi selecting L_9 orthogonal array is being carried out. Oil samples were prepared by adding viscosity index improver. The experiments were preformed in room temperature for different experimental combination for different oil samples. The experiments were performed three times for each run and average of damping coefficient and kinematic viscosity was used for the modeling.

A. Selection of Viscous fluids

The viscous fluids are engine oil of viscosity grade SAE10W30, SAE15W40 and SAE20W50 used in four stroke engine, with and without additives for obtaining the damping coefficient.

The physical properties of engine oil are shown below in Table-I as

Table I. Typical Properties of Engine Oil

Sr. No	Properties	Values		
		10W30	15W40	20W50
1	Density @ 15C g/ml	0.72	0.8	0.88
2	Viscosity index	150	140	121
3	Viscosity, Kinematic @ 100C mm^2/s	10.5	14	17.5
4	Viscosity, Kinematic @ 40C mm^2/s	68	107	158.1

B. Selection of Additives

Copolymers of ethylene and propylene are called olefin copolymers. The optimum ratio of ethylene-propylene contributes to thickening efficiency. The viscosity of a solvent increases by a higher content of ethylene. OCP has an important application in engine oils due to high viscosity. The advantage of OCP viscosity index improvers is available in low price. The physical properties of additives are shown below in Table-II as

Table II. Typical Properties of Additive (OCP)

Sr. No	Properties	Values	
		Palco(A1)	SPEL(A2)
1	Appearance	Light golden	Clear to hazy greenish tan
2	Viscosity, Kinematic @ 100C mm^2/s	160	200
3	Viscosity, Kinematic @ 40C mm^2/s	2200	2750

C. Design of Experiment (DOE)

In this study, the Taguchi method consisting of L_9 orthogonal arrays was used. Parameters taken for DOE are shown in Table III. Orthogonal design for determining the relation between damping coefficient and kinematic viscosity of oil is indicated in Table IV

Table III. Parameters

Level	Oil Grades	%wt Additive
1	SAE10W30	5
2	SAE15W40	10
3	SAE20W50	15

Table IV. Taguchi Array

Experiment No.	Oil Grades	%wt Additive
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

D. Experimental Apparatus and Procedure

The apparatus for measuring damping coefficient consist of a drum container, freely vibrating disc, wire, etc.

With no oil in the container allow the disc to oscillate and measure the time for some oscillation. Put oil in the drum and note the depth of immersion. Put the sketching pen in the bracket. Allow the disc to vibrate. Allow the pen to descend and see that it is in contact with the paper. Determine amplitude (x_n) at any position and amplitude(x).

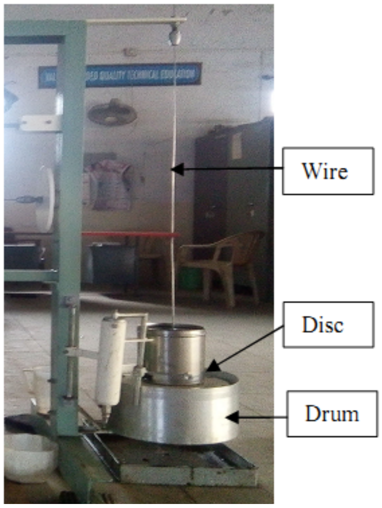

Fig. 1. Apparatus for Free Vibration Testing of Engine Oil

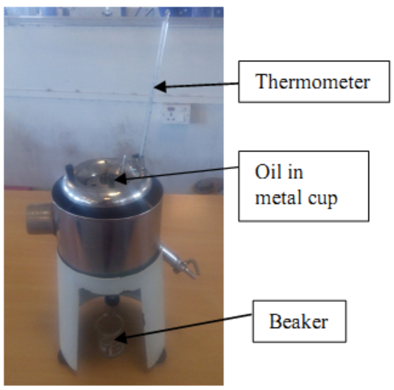

Fig.2. Apparatus for Kinematic Viscosity testing of Engine Oil

The apparatus for measuring kinematic viscosity is known as Redwood viscometer. Redwood viscometer consists of a metal cup with an axially placed orifice in the base. A metal ball or a rod can be used to close the hole. Clean the oil cup with a suitable solvent thoroughly and dry it using soft tissue paper. Keep the ball valve in its position so as to keep the orifice closed. The oil whose viscosity is to be determined is taken into the oil cup up to the mark. Remove the ball valve and simultaneously start a stopwatch. Note down the time taken in Redwood seconds for a collection of 50ml oil with a stopwatch at the room temperature without electric supply. During the collection of oil don't stir the bath.

V. Calculations

A. Torsional system with viscous damping

For a single-degree-of-freedom torsional system with a viscous damper, the viscous damping torque is given by[1]

$$T = -c\ddot{\theta} \qquad (1)$$

where, c is the torsional viscous damping constant, $\ddot{\theta}$ is the angular velocity of the disc, and the negative sign denotes that the damping torque is opposite the direction of angular velocity. The equation of motion can be derived as

$$J\ddot{\theta} + c\dot{\theta} + k_t\theta = 0 \qquad (2)$$

where, J = moment of inertia of the disc, k_t = spring constant of the system (restoring torque per unit angular displacement), and θ = angular displacement of disc. In the underdamped case, the frequency of damped vibration is given by

$$\omega_d = (1-\xi^2)^{1/2}\,\omega_n \qquad (3)$$

where,

$$\omega_n = (k_t/J)^{1/2} \qquad (4)$$

And,

$$\xi = c/c_c = c/2\,J\,\omega_n = c/2(k_t\,J) \qquad (5)$$

where, c_c is the critical damping constant.

B. Given data and Formulae for damping coefficient

Mass (m) = 6.3 kg
Diameter of container (D) = 25cm
Diameter of wire (d) = 0.3cm
Length of wire (L) = 120cm
Here, polar moment of inertia $(J) = (\pi d^4)/32$
$= 7.952\text{x}10^{-4}\ \text{cm}^4$
Moment of inertia $(I) = mk^2$
$= 492.18\text{kg.cm}^2$
Hence, $k_t = (G\,J)/L$
$= 5.0313\text{N/cm}^2$
Therefore, Critical damping co-efficient $(c_c) = (4\,k_t\,I)^{1/2}$
= 102.16
where, G = Modulus of rigidity

C. Given data and Formulae for kinematic viscosity

These Redwood seconds are converted into mm^2/sec of kinematic viscosity using the empirical formula

$\nu = AT - (B/T)$ x100

where A and B are viscometer constants and T is Redwood seconds.

A= 0.0026, B= 1.75

VI. Results and Discussion

Free Vibration test of air

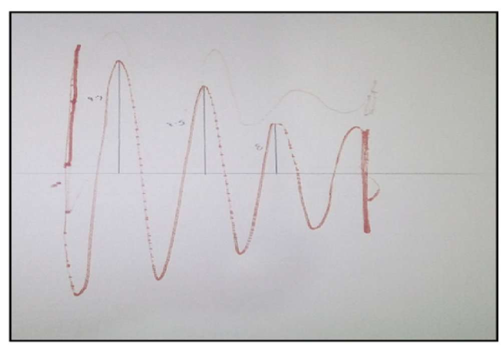

Fig.3. Amplitude of free vibration of disc in air

Logarithmic decrement $(\delta) = ln(x_1/x_2)$
Damping co-efficient $(c) = (\delta\,c_c)/2\pi$

Similarly, damping coefficients of oil samples with and without both additives are determined separately. Fig. 4, 5, 6 shows the damping coefficient of SAE10W30, SAE15W40 and SAE20W50 oil samples respectively with additives 1 & 2 and Fig. 7, 8, 9 shows the kinematic viscosity of SAE10W30, SAE15W40 and SAE20W50 oil samples respectively with additives 1 & 2.

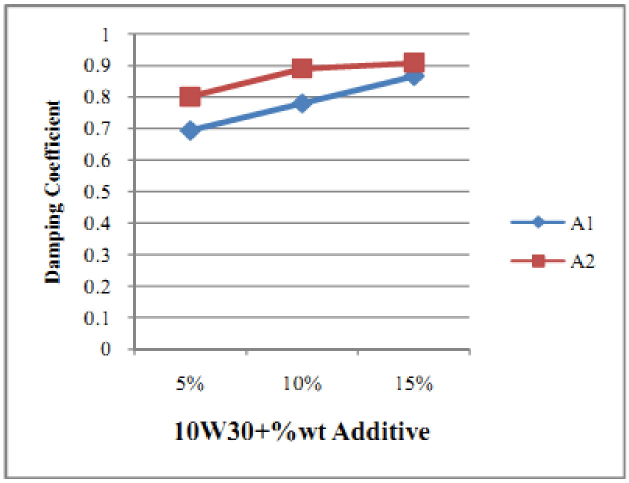

Fig.4. Damping Coefficient of 10W30 with Additive 1&2

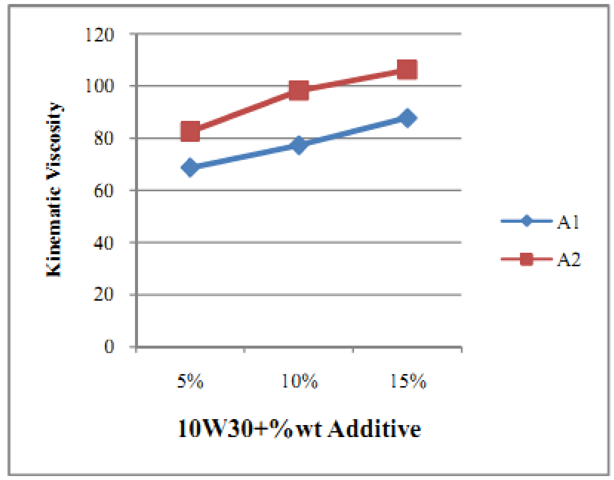

Fig.7. Kinematic Viscosity of 10W30 with Additive 1&2

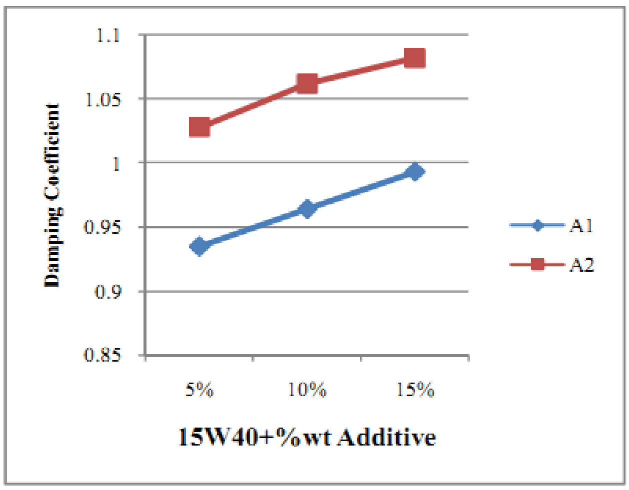

Fig.5. Damping Coefficient of 15W40 with Additive 1&2

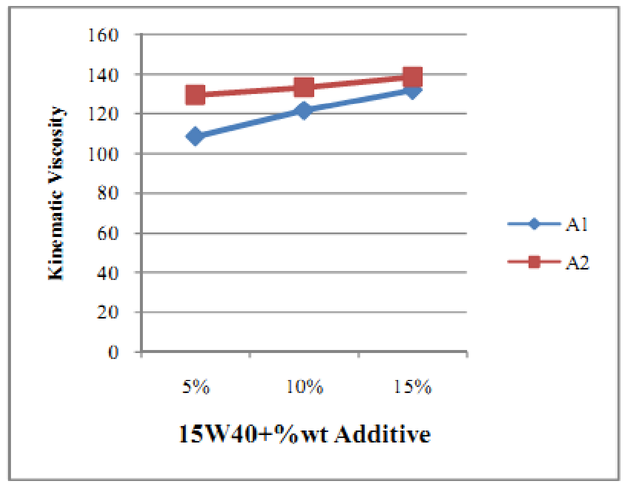

Fig.8. Kinematic Viscosity of 15W40 with Additive 1&2

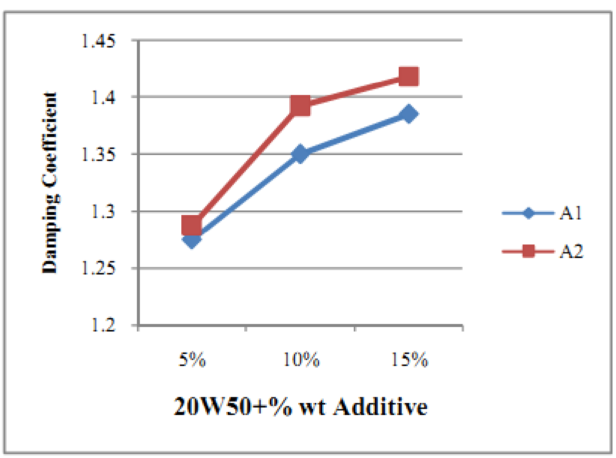

Fig.6. Damping Coefficient of 20W50 with Additive 1&2

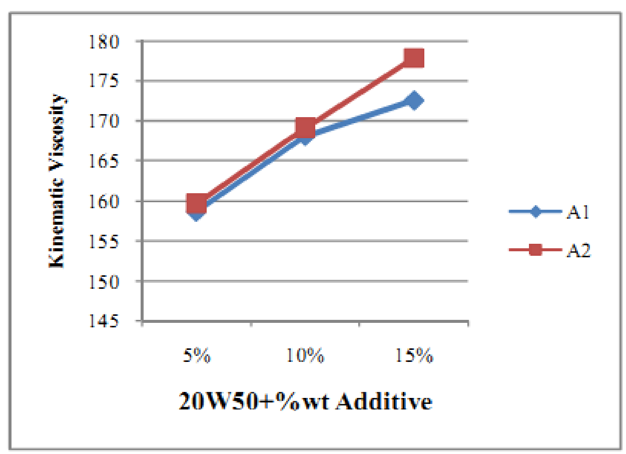

Fig.9. Kinematic Viscosity of 20W50 with Additive 1&2

The correlation between damping coefficient and kinematic viscosity of oil samples with additive 1 is

$$c = 0.264 + 0.00627v \quad \text{(I)}$$

The correlation between damping coefficient and kinematic viscosity of oil samples with additive 2 is

$$c = 0.205 + 0.00671v \quad \text{(II)}$$

Validation of the regression correlation is given in following Table V.

Table V. Validation of Regression Analysis

			Damping Coefficient (c) Ns/mm	
Sr. No	Oil Grades	Kinematic Viscosity (v) mm^2/s	Experimental	Regression
1	SAE10W30	68	0.72	0.67582
2	SAE15W40	107	0.98	0.92893
3	SAE20W50	158.1	1.32	1.27557

VII. Conclusion

Engine oil are tested in order to verify differences in damping coefficient and kinematic viscosity when two additives with different percentage weight are mixed. The main conclusions are:

- Damping coefficient of oil samples with additive 2 is greater than oil samples with additive 1.
- Kinematic viscosity of oil sample with additive 2 is greater than oil samples with additive 1.
- It can be seen that damping coefficient is directly proportional to kinematic viscosity.
- From the above results it is seen that the average value of all errors is 0.9% which is very negligible.
- Both experimental model and regression analysis model shows good results with minimum percentage of error.
- Maximum damping effect can be obtained with higher damping coefficient of SAE20W50 with additive 2.

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