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Kinematic Viscosity and Shear Stress of Used Engine Oil

Vojtěch Kumbár, Petr Dostál and Jiří Votava

Department of Engineering and Automobile Transport, Faculty of Agriculture, Mendel University in Brno, Brno 613 00, Czech Republic

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Abstract: The goal of this paper describes kinematic viscosity and shear stress of two used engine oils, which have been taken from two different passenger cars. Kinematic viscosity and shear stress are two of the most important physical behaviours of fluids, especially lubricating fluids. In this paper the authors have focused on engine oil. Knowledge of these properties of engine oil is very important due to its lifetime. The experiments have been done using digital rotary rheometer Anton Paar DV-3 P with use of TR8 spindle and special adapter for a small amount of sample (20 mL). Two different engine oils have been observed—first from passenger car Renault Scenic with petrol engine (engine capacity 1.6 dm^3) and the second from passenger car Škoda Roomster with diesel engine (engine capacity 1.4 dm^3). Castrol Magnatec 10W-40 engine oil has been taken from Renault car and Shell Helix Ultra Extra 5W-30 engine oil has been taken from Škoda car. Service interval of change oil has been set to 15,000 km and samples of used engine oils have been taken after 1,500 km. Only first samples of used engine oils have been taken after raid of 20 km. All samples of used engine oils have been compared with new (unused) engine oils same specification. The measured values of kinematic viscosity and shear stress have been modeled using linear function. The coefficients of correlation *R* have been achieved high values (0.88-0.96). The obtained models can be used to prediction of engine oil flow behaviour.

Key words: Kinematic viscosity, shear stress, engine oil, raid, modeled.

1. Introduction

Engine oil or motor oil, is oil used for lubrication of various internal combustion engines. While the main function is to lubricate moving parts, engine oil also cleans, inhibits corrosion, improves sealing and cools engine by carrying heat away from the moving parts. Engine oils are derived from petroleum and non-petroleum synthesized chemical compounds used to make synthetic oil. Engine oil mostly consists of hydrocarbons and organic compounds consisting entirely of carbon and hydrogen [1].

For satisfactory lubrication of the engine, the oil should possess some functional properties of which viscosity of oil is one of the most important properties, as it brings out the oil's capacity to lubricate [2]. That is why the first lubricant standard J300 which was developed by SAE (Society for Automotive Engineer) in 1911 was Viscosity Classification of Motor Oils, and although this standard was revised and updated many times it is still used today worldwide for motor oil applications. Now a kind of oil's viscosity is identified by its SAE number. The thinner the oil, the lower its number is, e.g., SAE 10W. The number relates to the viscosity at particular temperature and the alphabet "W" indicates the oil's suitability for colder temperature. With the viscosity index improver, the viscosity increases at higher temperature and at lower temperature it does not increase significantly, thus achieving optimum viscosity at lower and higher temperatures. Such oils are called multi-grade oils, for instance, "20W-40" shows thinness at low temperature and thickness at higher temperature [3].

However, there is other service classification of oil apart from viscosity, developed by API (American Petroleum Institute), which indicates service characteristics. It is graded on a scale from SA (the lowest) to SJ (the highest) for gasoline engines; it is

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Corresponding author: Vojtěch Kumbár, Eng. (doctoral student) and teaching assistant, research field: tribology and fluid mechanics. E-mail: vojtech.kumbar@mendelu.cz.

also graded on a scale from CA to CG [4]. Both the recommendations for viscosity and service classification can be found on label of the oil containers.

The following are general recommendations applied [5]:

(1) SAE viscosity grade engine oil: 5W-30. Temperature conditions: below -18 °C. Description: provides excellent fuel economy and low temperature performance in most late-model engines. Especially recommended for new car engines.

(2) SAE viscosity grade engine oil: 10W-30. Temperature conditions: above -18 °C. Description: most frequently recommended engine oil viscosity grade for most automobile engines, including high-performance multivalve engines and turbo-charged engines.

(3) SAE viscosity grade engine oil: 10W-40. Temperature conditions: above -18 °C. Description: the first multi-grade introduced. A good choice for controlling engine wear and preventing oil breakdown from oxidation.

(4) SAE viscosity grade engine oil: 20W-50. Temperature conditions: above -7 °C. Description: provides maximum protection for high-performance, high-RPM racing engines. Excellent choice for high temperature and heavy loads such as driving in the desert or towing a trailer at high speeds for long periods of time.

(5) SAE viscosity grade engine oil: SAE 30 & SAE 40. Temperature conditions: above 5 °C & above 16 °C. Description: for cars and light trucks, where recommended by manufacturers. Not recommended when cold-temperature starting is required.

Adding anything foreign to the oil can change its viscosity. Some types of after-market oil additives cause a quite high viscosity at operating temperature. While an additive might improve bearing wear, it can often cause poorer upper-end wear. Other changes to viscosity can result from contamination of the oil. Moisture and fuel can both cause the viscosity to increase or decrease, depending on the contaminant and how long it has been present in the oil. Antifreeze often increases oil's viscosity. Exposure to excessive heat (leaving the oil in use too long, engine overheating) can also increase viscosity [6].

There are several different methods for measuring oil's viscosity. Except traditional methods (such as capillary, falling ball, rotary, etc.)—described in Refs. [7, 8] or Ref. [9] in detail, there are new approaches described, e.g., in Refs. [10, 11], or Ref. [12].

Fluid temperature stability is essential to the success of mechanical systems. All lubricating fluids have practical limits on the acceptable operating temperature range—both high and low levels. The machine loses stability and experiences conditional failure whenever the system's fluid temperature violates these limits. The conditional failure can ultimately results conducts to degradation of machine components. Temperature extremes have a pronounced effect on component materials as well as machine performance. When temperature is too low, fluid viscosity is high. At low temperatures, the fluid often reaches the point where it actually congeals and will no longer flow (pour point). High temperature also accelerates wear, destroys hydrodynamic lubrication regimes, increases the oxidation rate, fosters additive depletion and affects other critical aspects of the machine.

Fluid temperature also grossly affects chemical stability and particularly the oxidation rate of the basic elements of the oil. The primary accelerator of all oxidation reactions is temperature. Like any other reaction, the oxidation rate of hydrocarbons will approximately double for every 18 °C increase in temperature. Below 60 °C, the reaction is comparatively slow, but the life of the oil is reduced 50% for every 15 °C temperature rise above 60 °C, according to the Arrhenius equation for chemical reaction rates. Hence, for high-temperature applications, the oxidation stability of the oil can have great significance [13].

The thermal stability of a fluid is its ability to resist decomposition due to temperature alone. It establishes the ultimate high-temperature limit for a tribological system fluid that will ensure continual unimpaired service. The most significant change in fluid properties caused by thermal decomposition of organic molecules is an increase in vapor pressure caused by the shearing of molecules into smaller, more volatile fragments.

This study considered the effects of variations in lubricant viscosity under different temperatures. Such knowledge is critical for description of processes running in the combustion engines. Quantification of variations in oil's viscosity during the engine cycle is useful for description of ring-pack friction and wear. The influence of viscosity on ring/liner friction stems from a trade-off between hydrodynamic and boundary effects—increased viscosity causes an increase in shear losses but a decrease in asperity contact and vice versa. Because other factors, such as piston speed, are changing throughout the engine cycle, the "ideal" viscosity that provides the lowest friction is also changing [14].

The shear stress is one of the most important behaviours of liquids, especially for technical liquids—engine oil, transmission oil, hydraulic oil, petrol, diesel and so on. It can be used to describe flow behaviour of liquids. For Newtonians fluids increases shear stress with increasing shear rate. More about this thesis is written in Ref. [15].

The shear stress causes that the engine oil film is maintained at the lubricated parts of the engine. Then all the engine components are therefore good lubricated. With decreasing values of shear stress of engine oil, the engine system may fail. Therefore, continuously monitoring of engine oil's shear stress is important [16].

The objective of this study is to describe kinematic viscosity and shear stress of two used engine oils, which have been taken from two different passenger cars. Kinematic viscosity and shear stress are two of the most important physical behaviours of fluids, especially lubricating fluids. In this study the authors have focused on engine oil.

2. Materials and Methods

Two different engine oils in two different passenger cars were observed. Specifications of engine oils are showed in Table 1 and specifications of vehicles are showed in Table 2.

The engine oil Castrol Magnatec 10W-40 was used in car Renault Scenic and the engine oil Shell Helix Ultra Extra 5W-30 was used in car Škoda Roomster. The samples of used engine oils were taken from engines after 1,500 km. First samples are taken with raid 20 km, because after drain old (used) engine oil from engine a rest of old (used) engine oil stay in engine and its parts. More of this problematic have been written by authors in their publication [17]. The delivery point was the oil dipstick for both passenger cars.

The procedure of sample preparation for shear stress and viscosity measurements corresponded to a typical sampling procedure. The adequate volume (20 mL) of oil was put into the apparatus cuvette without previous heavy mixing or any other kind of preparation.

Table 1 Specifications of engine oils.

Producer	Designation	Viscosity class	Performance class
Castrol	Magnatec	10W-40	ACEA A3/B3/B4, API SL/CF
Shell	Helix ultra extra	5W-30	ACEA C2/C3 (A3/B3/B4)

Table 2 Specifications of passenger cars.

Producer	Type	Engine	Turbocharger	Cylinder volume (cm^3)	Number of cylinders	Engine power (kW)
Renault	Scenic I	Gasoline	No	1,600	4	79
Škoda	Roomster	Diesel	Yes	1,400	3	51

There are several methods to measure shear stress and kinematic viscosity of fluid or semi fluid materials and different geometries may be utilized: concentric cylinders, cone and plate, and parallel plates.

Presented data have been obtained from measurements performed on laboratory digital rheometer Anton Paar DV-3 P (Austria), which is designed to measure dynamic or kinematic viscosity, shear stress and shear rate. The DV-3 P is a rotational rheometer, based on measuring the torque of a spindle rotating in the sample at a given speed. Shear stress is expressed in $g \cdot cm^{-1} \cdot s^{-2}$, shear rate in s^{-1}, kinematic viscosity in $mm^2 \cdot s^{-1}$, and speed of spindle in revolutions/min (rpm). The experiments have been performed with use of TR8 spindle with special adapter for a small amount of samples. Due to the parallel cylinder geometry, shear stress and kinematic viscosity, except other values, can be determined. Kinematic viscosity is the ratio of absolute or dynamic viscosity to density—a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density.

$$\nu = \frac{\eta}{\rho} \ [\mathrm{mm^2 \cdot s^{-1};\ mPa \cdot s,\ kg \cdot m^{-3}}] \qquad (1)$$

where, ν = kinematic viscosity;

η = absolute or dynamic viscosity;

ρ = density.

In the SI-system the theoretical unit is m^2/s or commonly used Stoke (St) [18].

Schematic of the measuring geometry is shown in Fig. 1.

3. Results and Discussion

The result values of kinematic viscosity and shear stress of automobile engine oil taken from gasoline engine (Renault Scenic) are showed in Table 3 and Fig. 2.

Result values were modeled using linear function. The general formula of linear function is:

$$y\ (x) = kx + q \qquad (2)$$

Valued formula for counting kinematic viscosity of automobile engine oil (gasoline engine) is:

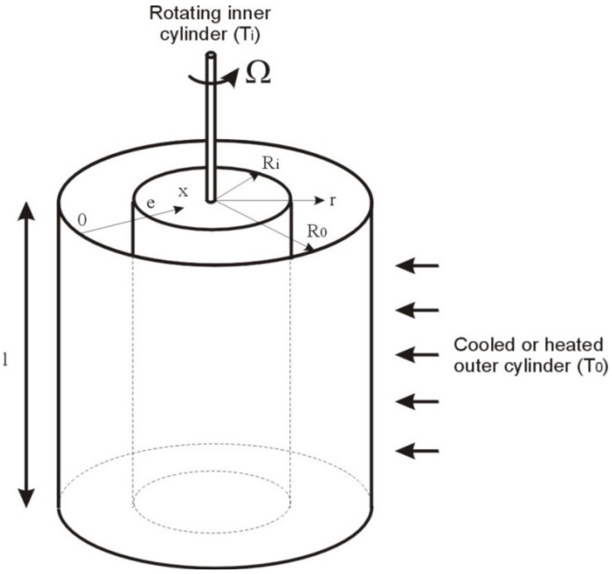

Fig. 1 Schematic of the measuring geometry [18].

Table 3 Kinematic viscosity and shear stress of engine oil (gasoline engine).

Raid (km)	Kinematic viscosity, ($mm^2 \cdot s^{-1}$)	Shear stress ($g \cdot cm^{-1} \cdot s^{-2}$)
0	214.96	172.33
20	212.80	170.59
1,737	204.56	169.99
3,097	201.79	161.76
4,462	199.29	159.76
6,053	198.12	158.82
7,550	196.88	157.55
9,104	196.40	157.45
11,027	195.97	157.10
12,079	195.06	156.37
13,815	194.73	156.10
15,108	193.59	155.60

$$\nu\ (s) = -0.0012 \cdot s + 208.56\ [\mathrm{mm^2 \cdot s^{-1};\ km}] \qquad (3)$$

where, ν is kinematic viscosity and s is raid.

Valued formula for counting shear stress of automobile engine oil (gasoline engine) is:

$$\tau\ (s) = -0.00102 \cdot s + 168.35\ [\mathrm{g \cdot cm^{-1} \cdot s^{-2};\ km}] \qquad (4)$$

where, τ is shear stress and s is raid. The values of correlation coefficients R were -0.88 (for both).

The result values of kinematic viscosity and shear stress of automobile engine oil taken from diesel engine (Škoda Roomster) are showed in Table 4 and Fig. 3.

Result values were modeled using Eq. (2) of linear function. Valued formula for counting kinematic

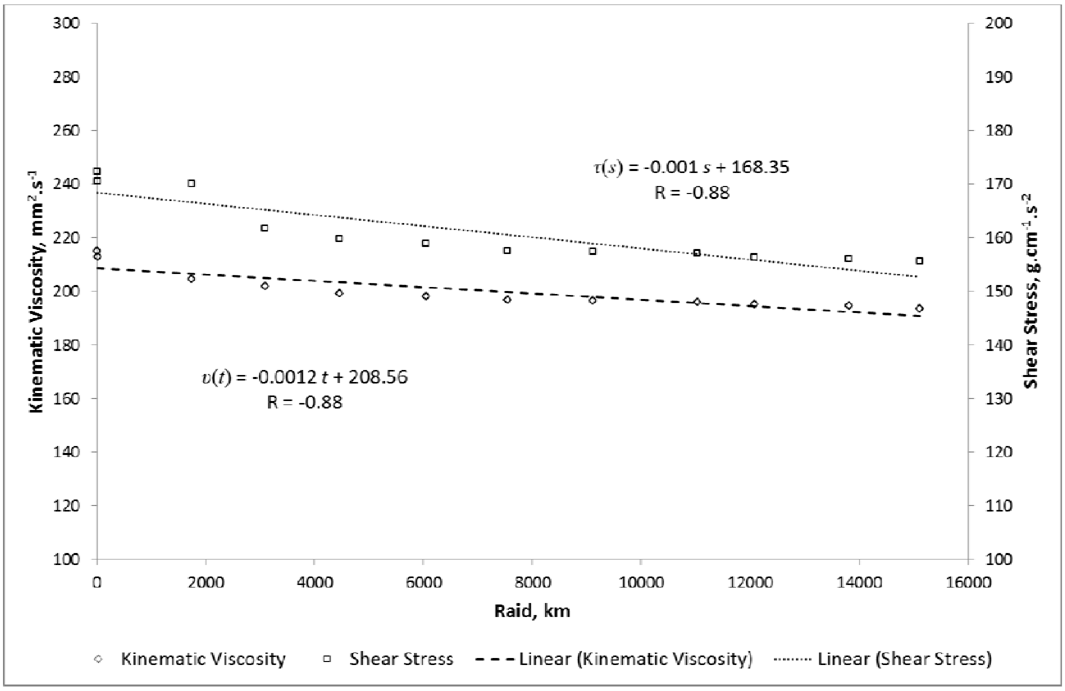

Fig. 2 Kinematic viscosity and shear stress of engine oil (gasoline engine).

Table 4 Kinematic viscosity and shear stress of engine oil (diesel engine).

Raid (km)	Kinematic viscosity ($\mathrm{mm}^2 \cdot \mathrm{s}^{-1}$)	Shear stress ($\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}$)
0	176.63	139.79
20	174.88	137.05
1,475	170.85	135.22
2,985	170.16	134.67
4,436	165.87	131.27
6,060	163.23	129.18
7,820	162.89	128.99
9,194	161.74	128.00
11,653	160.20	127.12

viscosity of automobile engine oil (diesel engine) is:

$$\nu\ (s) = -0.0014 \cdot s + 174.04\ [\mathrm{mm}^2 \cdot \mathrm{s}^{-1}; \mathrm{km}] \tag{5}$$

Where v is kinematic viscosity and s is raid.

Valued formula for counting shear stress of automobile engine oil (diesel engine) is:

$$\tau\ (s) = -0.00101 \cdot s + 137.32\ [\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2};\ \mathrm{km}] \tag{6}$$

where, τ is shear stress and s is raid. The values of correlation coefficients R were -0.95 and -0.96.

With increasing count of the kilometres (raid) the kinematic viscosity and shear stress of engine oil (both type of engines) decreased. The kinematic viscosity of engine oil Castrol Magnatec 10W-40 (taken from gasoline engine) decreased from 214.96 $\mathrm{mm}^2 \cdot \mathrm{s}^{-1}$ to 193.59 $\mathrm{mm}^2 \cdot \mathrm{s}^{-1}$. It is a decrease of 9.9%. The kinematic viscosity of engine oil Shell Helix Ultra Extra 5W-30 (taken from diesel engine) decreased from 176.63 $\mathrm{mm}^2 \cdot \mathrm{s}^{-1}$ to 160.20 $\mathrm{mm}^2 \cdot \mathrm{s}^{-1}$. It is a decrease of 9.3% in kinematic viscosity, but the raid there was only 11,653 km. If we calculate kinematic viscosity (Eq. (5)) in raid 15,000 km, the value of kinematic viscosity is 153.04 $\mathrm{mm}^2 \cdot \mathrm{s}^{-1}$. It is a decrease of 13.4 % in kinematic viscosity.

The shear stress of engine oil Castrol Magnatec 10W-40 (taken from gasoline engine) decreased from 172.33 $\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}$ to 155.60 $\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}$. It is a decrease of 9.7%. The shear stress of engine oil Shell Helix Ultra Extra 5W-30 (taken from diesel engine) decreased from 139.79 $\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}$ to 127.12 $\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}$. It is a decrease of 9.1%., but the raid there was only 11,653 km. If calculate shear stress (Eq. (6)) in raid 15,000 km, the value of shear stress is 122.32 $\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}$. It is a decrease of 13.5 % in shear stress.

Created mathematical models achieve high accuracy. The obtained trends are descriptive and

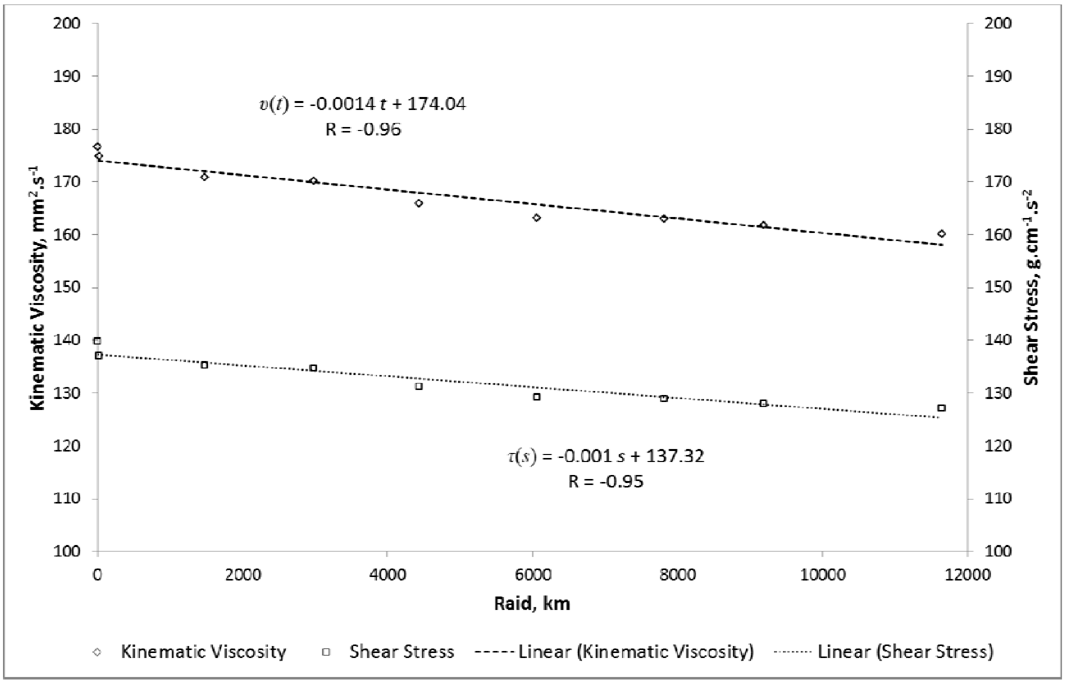

Fig. 3 Kinematic viscosity and shear stress of engine oil (diesel engine).

predict the behaviour of kinematic viscosity and shear stress, especially the dependence on the raid. These trends were compared with results of other authors [19, 20], and they achieved similar trends.

4. Conclusions

Engine oil lubricates, cleans, inhibits corrosion, improves sealing and cools engine by carrying heat away from the moving parts. This study is primarily focused on quantification of how the kinematic viscosity and shear stress of engine oil changes with raid. Two different commercially distributed engine oils were used: Castrol Magnatec 10W-40 and Shell Helix Ultra Extra 5W-30. Samples of used engine oil were taken from two vehicles—with gasoline engine (Renault Scenic) and diesel engine (Škoda Roomster).

The kinematic viscosity of engine oil Castrol Magnatec 10W-40 (taken from gasoline engine) decreased 9.9%. The kinematic viscosity of engine oil Shell Helix Ultra Extra 5W-30 (taken from diesel engine) decreased 9.3%, but the raid there was only 11,653 km. If calculate kinematic viscosity (Eq. (5)) in raid 15,000 km, the kinematic viscosity decreases 13.4%.

The shear stress of engine oil Castrol Magnatec 10W-40 (taken from gasoline engine) decreased 9.7%. The shear stress of engine oil Shell Helix Ultra Extra 5W-30 (taken from diesel engine) decreased 9.1%, but the raid there was only 11,653 km. If calculate shear stress (Eq. (6)) in raid 15,000 km, the shear stress decreases 13.5%.

The result values were modeled using linear mathematical model. Correlation coefficients R achieved high values—from 0.88 to 0.96. The obtained trends are descriptive and predict the behaviour of kinematic viscosity and shear stress, especially the dependence on the raid.

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