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DIFFERENCES IN ENGINE OIL DEGRADATION IN SPARK-IGNITION AND COMPRESSION-IGNITION ENGINE

ROZBIEŻNA DEGRADACJA OLEJU SILNIKOWEGO PRZY ZASTOSOWANIU W SILNIKU O ZAPŁONIE WYMUSZONYM I W SILNIKU WYSOKOPRĘŻNYM

This paper deals with differences in engine oil degradation in spark-ignition (SI) engine and compression-ignition (CI) engine. Three important physical-mechanical behaviours were observed – dynamic viscosity, kinematic viscosity, and shear stress. These behaviours of lubricant may influence reliability of entire engine. It must be monitored engine oil condition in suitable intervals. Article describes these issues for two engine oils taken from two different passenger cars – with SI engine and with CI engine. The experiments have been done using digital rotary rheometer Anton Paar DV-3P with use of standard TR8 spindle and special adapter for a small amount of sample. 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 from both engines. All samples of used engine oils have been compared with new engine oils same specification – it is the best method to degradation detection. The measured values of dynamic viscosity, kinematic viscosity and shear stress have been modeled using elementary mathematical model – linear function. The absolute values of correlation coefficients, r, and coefficient of determination, R2, have been achieved very high values. The obtained mathematical models can be used to prediction of engine oil flow behaviour and can increased engine reliability.

***Keywords**: degradation, engine, lubricant, reliability, modelling.*

Niniejszy artykuł opisuje odrębne degradacje oleju silnikowego przy zastosowaniu w silniku o zapłonie wymuszonym oraz w silniku wysokoprężnym. Analizowane zostały trzy bardzo ważne właściwości fizyczne – lepkość dynamiczna, kinematyczna oraz naprężenie ścinające. Właściwości te mogą wpływać na niezawodność całego sinika, i dla tego jest ważnym kontynualne obserwowanie stanu degradacji oleju silnikowego. W ramach niniejszego eksperymentu zostały obserwowane dwa oleje silnikowe z odmienną klasą lepkości, które zostały pobrane z dwu różnych samochodów osobowych – z silnikiem o zapłonie wymuszonym i z silnikiem wysokoprężnym. Lepkość olejów została zmierzona przy pomocy cyfrowego lepkościomierza obrotowego Anton Paar DV-3P z standardowym wrzecionem TR8 oraz z adapterem do mierzenia małych próbek. Interwał serwisowy wymiany oleju silnikowego został określony na 15000 km a poszczególne próbki były z silnika odbierane kontynualnie po 1500 km. Wszystkie próbki użytego oleju silnikowego zostały porównane z próbkami oleju nowego z tą samą specyfikacją. Metoda ta jest najbardziej przydatną do określenia stanu degradacji oleju. Zmierzone wartości lepkości dynamicznej, lepkości kinematycznej oraz naprężenie ścinającego zostały następnie podane modelowaniu przy pomocy podstawowego modelu matematycznego – funkcja liniowa. Wartości bezwzględne współczynnika korelacji, r, i współczynnika determinacji, R2, osiągały bardzo wysokich wartości. Sformowane modele matematyczne mogą służyć do predykcji zachowywania się zastosowanego oleju silnikowego przy płynięciu oraz do podwyższenia niezawodności całego silnika.

***Słowa kluczowe**: degradacja, silnik, smar, niezawodność, modelowanie.*

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 Society for Automotive Engineer (SAE) 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 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 turbocharged 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. Temperatureconditions: 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.) – are 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. We can use it 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 may fail of engine system. Therefore, continuously monitoring of engine oil's shear stress is important [16].

The objective of this study is to describe differences indynamic viscosity, kinematic viscosity, and shear stress of two used engine oils, which have been taken from two different passenger cars (with SI engine and CI engine). Dynamic viscosity, kinematic viscosity, and shear stress are the most important physical behaviours of lubricants.

2. Materials and experimental methods

Two different engine oils in two different passenger cars were observed. Specifications of engine oils are showed in Table1 and specifications of vehicles are showed in Table 2.

The engine oil with viscosity class 10W-40 was used in car with gasoline engine and the engine oil with viscosity class 5W-30 was used in car with diesel engine. The samples of used engine oils were taken from engines after 1,500km. More of this problematic have been written by authors in their publication [17]. The delivery point was the oil dipstick for both passenger cars.

Table 1. Specifications of engine oils

Sample	Viscosity class	Performance class
Oil_1	10W-40	ACEA A3/B3/B4, API SL/CF
Oil_2	5W-30	ACEA C2/C3 (A3/B3/B4)

Table 2. Specifications of passenger cars

Sample	Engine	Turbocharger	Cylinder volume,cm^3	Number of cylinders	Engine power, kW
Car_1	Spark-ignition	No	1,600	4	79
Car_2	Compression-ignition	Yes	1,400	3	51

The procedure of sample preparation for shear stress and viscosity measurements corresponded toatypical 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. 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-3P (Austria), which is designed to measure dynamic or kinematic viscosity, shear stress and shear rate. The DV-3P 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/minute [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 densitya quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density:

$$v = \frac{\eta}{\rho} \qquad (1)$$

where v is kinematic viscosity, η is absolute or dynamic viscosity, and ρ is density. In the SI-system the theoretical unit is $m^{2} \cdot s^{-1}$ or commonly used Stoke (St)[18].

Shear stress can be obtained by dividing the absolute viscosity of a fluid with its mass density [19]:

$$\tau = \eta \frac{du}{dx} = h\ D = h\dot{\gamma} \qquad (2)$$

where τ is shear stress, η is absolute or dynamic viscosity, and D is shear rate.In the SI-system the theoretical unit is Pa or $g \cdot cm^{-1} \cdot s^{-2}$.

Dynamic and kinematic viscosity of oils was measured in temperature 15°C and density of oils was measured in standard temperature 40°C according the ISO standard [20].

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

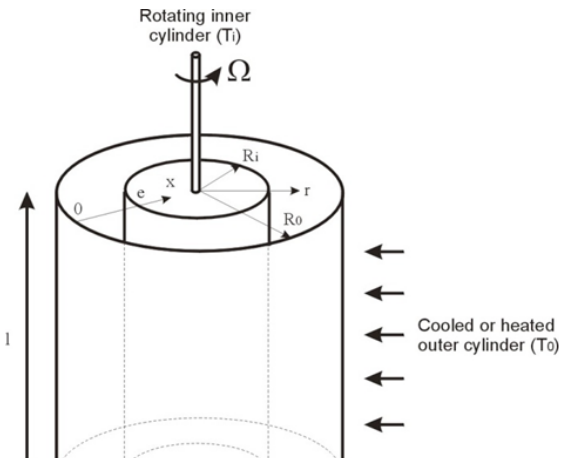

Fig. 1. Schematic of the measuring geometry

3. Results and discussion

The degradation of engine oil used in different types of engine is described by its physical properties. The result values of dynamic viscosity and kinematic viscosity of automobile engine oil taken from SI engine are seen in Table3 and showed in Fig. 2 and Fig. 3. The values of density were measured on 0.862 $g \cdot cm^{-3}$ (for Oil_1) and 0.851 $g \cdot cm^{-3}$ (for Oil_2), which is used to determination values of kinematic viscosity.

Table 3. Dynamic viscosity and kinematic viscosity of engine oil – Oil_1 (SI engine)

Raid, km	Dynamicviscosity, mPa·s	Kinematic viscosity, $mm^{2} \cdot s^{-1}$
0	178.40	206.96
1,737	175.47	203.56
3,097	173.94	201.79
4,462	172.37	199.97
6,053	170.78	198.12
7,550	169.71	196.88
9,104	169.30	196.40
11,027	168.93	195.97
12,079	168.14	195.06
13,608	167.12	193.87
14,971	166.07	192.66

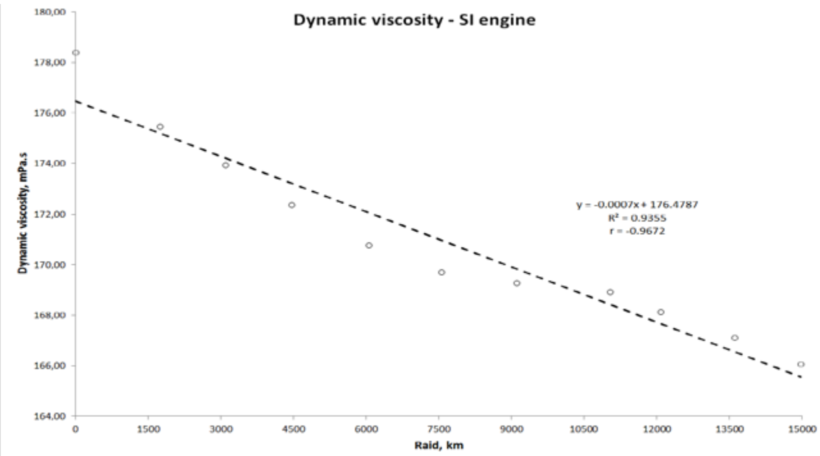

Fig. 2. Dynamic viscosity of engine oil – Oil_1 (SI engine)

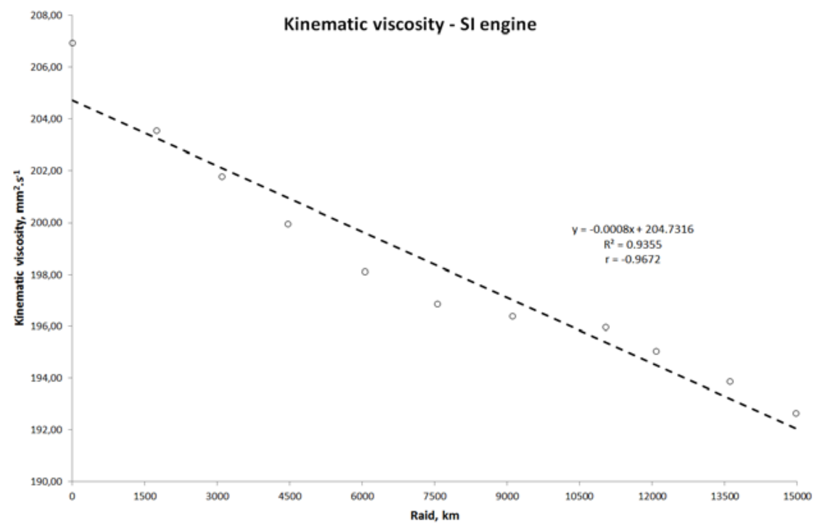

Fig. 3. Kinematic viscosity of engine oil – Oil_1 (SI engine)

Result values of dynamic and kinematic viscosity of Oil_1 (taken from SI engine) were modeled using linear function. The general equation of linear function is:

$$y(x) = k \cdot x + q \quad (3)$$

Equation for counting dynamic viscosity of engine oil (SI engine) is:

$$\eta(s) = -0.0007 \cdot s + 176.4787 [mPa \cdot s; km] \quad (4)$$

where η is dynamic viscosity and s is raid. The absolute value of correlation coefficient, r, is 0.9672 and value of coefficient of determination, R^2, is 0.9355.

Equation for counting kinematic viscosity of engine oil (SI engine) is:

$$\eta(s) = -0.0008 \cdot s + 204.7316 \left[mm^2 \cdot s^{-1}; km \right] \quad (5)$$

where v is kinematic viscosity and s is raid. The absolute value of correlation coefficients, r, is 0.9672 and value of coefficient of determination, R^2, is 0.9355.

For SI engine and Oil_1 we can state:

- With increasing count of the kilometers (raid) the dynamic viscosity of Oil_1 decreased. The dynamic viscosity of Oil_1 (taken from SI engine) decreased from the 178.40mPa·s to 166.07mPa·s. It means a decrease of 6.911% using Eq. (6).
- With increasing count of the kilometers (raid) the kinematic viscosity of Oil_1 decreased. The kinematic viscosity of Oil_1 (taken from SI engine) decreased from the 206.96 $mm^2 \cdot s^{-1}$ to 192.66 $mm^2 \cdot s^{-1}$. It is a decrease of 6.909% using Eq. (6).

$$Decrease = \left(1 - \frac{value\ inraid_{max}}{value\ inraid_{min}} \right) \cdot 100\% \quad (6)$$

The result values of dynamic viscosity and kinematic viscosity of automobile engine oil taken from CI engine are seen in Table 4 and showed Fig. 4 and Fig. 5.

Table 4. Dynamic viscosity and kinematic viscosity of engine oil – Oil_2 (CI engine)

Raid, km	Dynamic viscosity, mPa·s	Kinematic viscosity, $mm^2 \cdot s^{-1}$
0	152.26	176.63
1,475	149.00	172.85
2,985	144.95	168.16
4,436	142.98	165.87
6,060	140.70	163.23
7,820	139.11	161.38
9,194	136.83	158.74
11,253	132.92	154.20
13,211	129.66	150.42
14,956	125.74	145.87

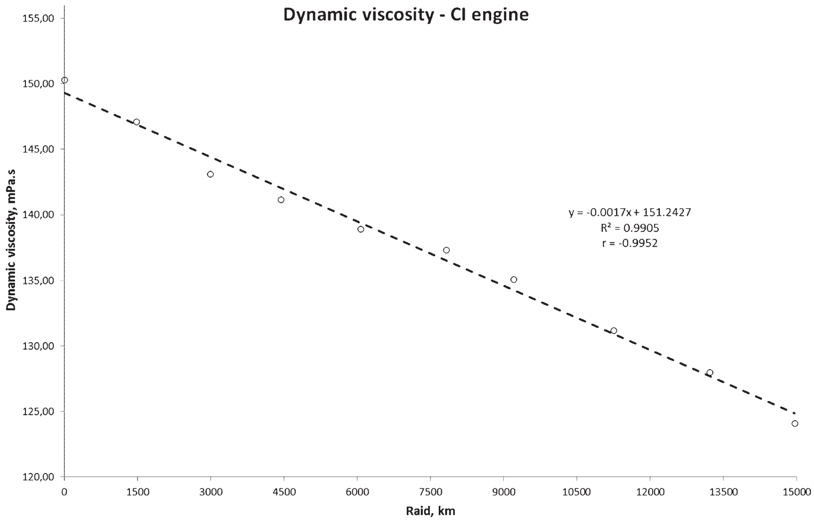

Fig. 4. Dynamic viscosity of engine oil – Oil_2 (CI engine)

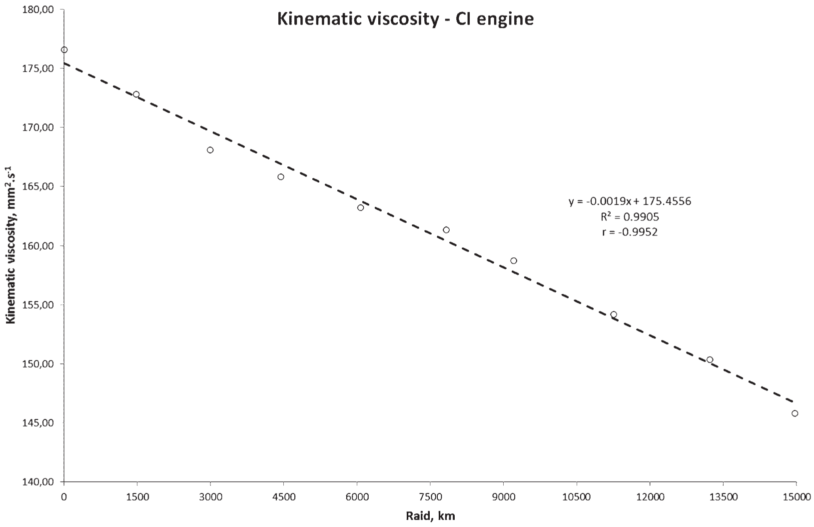

Fig. 5. Kinematic viscosity of engine oil – Oil_2 (CI engine)

Result values of dynamic and kinematic viscosity of Oil_2 (taken from CI engine) were modeled using linear function. The general equation of linear function is same as Eq. (3). Equation for counting dynamic viscosity of engine oil (CI engine) is:

$$\eta(s) = -0.0017 \cdot s + 151.2427 [mPa \cdot s; km] \quad (7)$$

where η is dynamic viscosity and s is raid. The absolute value of correlation coefficient, r, is 0.9952 and value of coefficient of determination, R^2, is 0.9905.

Equation for counting kinematic viscosity of engine oil (CI engine) is:

$$v(s) = -0.0019 \cdot s + 175.4556 \left[mm^2 \cdot s^{-1}; km \right] \quad (8)$$

where v is kinematic viscosity and s is raid. The absolute value of correlation coefficients, r, is 0.9952 and value of coefficient of determination, R^2, is 0.9905.

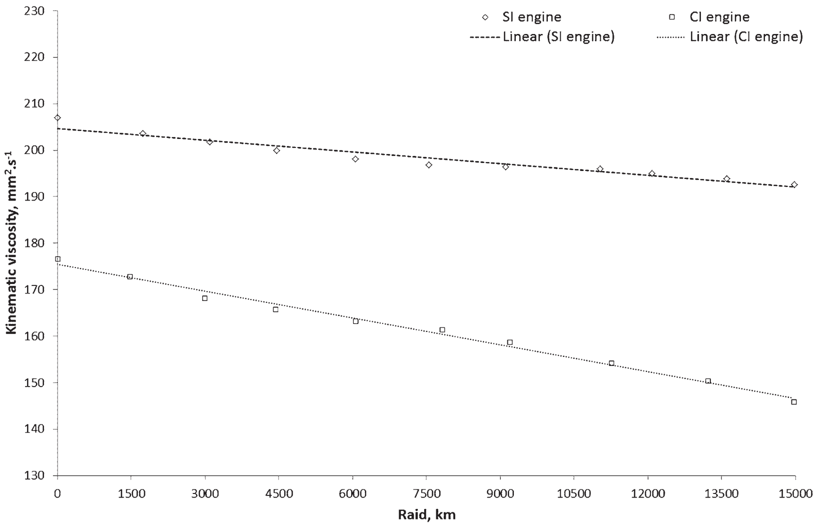

Fig. 6. Kinematic viscosityof engine oils– Oil_1 and Oil_2 (SI and CI engine)

For CI engine and Oil_2 we can state:

- With increasing count of the kilometers (raid) the dynamic viscosity of Oil_2 decreased. The dynamic viscosity of Oil_2 (taken from CI engine) decreased from the 152.26 mPa·s to 125.74 mPa·s. It means a decrease of 17.418%using Eq. (6).
- With increasing count of the kilometers (raid) the kinematic viscosity of Oil_2 decreased. The kinematic viscosity of Oil_2(taken from CI engine) decreased from the 176.63 $mm^2 \cdot s^{-1}$ to 145.87 $mm^2 \cdot s^{-1}$. It is a decrease of 17.415%using Eq. (6).

Eq. 6 is created by way of contrast of kinematic viscosities of both engine oils taken from SI and CI engine.

The result values of shear stress (in shear rate $\dot{\gamma}$ = 93 s^{-1}) of automobile engine oil taken from SI engine are seen in Table5 and showed in Fig. 7.

Table 5. Shear stress of engine oil – Oil_1 (SI engine)

Raid, km	Shear stress, $g \cdot cm^{-1} \cdot s^{-2}$
0	167.33
1,737	165.09
3,097	161.76
4,462	159.76
6,053	158.82
7,550	157.55
9,104	157.45
11,027	157.10
12,079	156.37
13,608	155.71
14,971	153.98

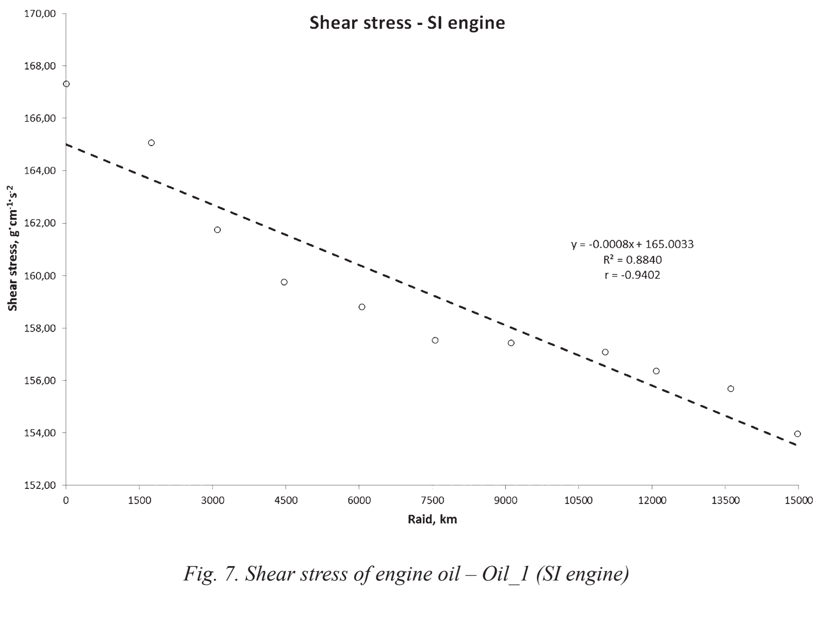

Fig. 7. Shear stress of engine oil – Oil_1 (SI engine)

Result values of shear stress of Oil_1 (taken from SI engine) were modeled using linear function. The general equation of linear function is same as Eq. (3). Equation for counting shear stress of engine oil (SI engine) is:

$$\tau(s) = -0.0017 \cdot s + 151.2427 \left[\text{g} \cdot \text{cm}^{-1} \cdot \text{s}^{-2}; km \right] \quad (9)$$

where τ is shear stress and s is raid. The absolute value of correlation coefficient, r, is 0.9402 and value of coefficient of determination, R^2, is 0.8840.

For SI engine and Oil_1 we can state:

- With increasing count of the kilometers (raid) the shear stress of Oil_1 decreased. The shear stress of Oil_1 (taken from SI engine) decreased from the 167.33$g \cdot cm^{-1} \cdot s^{-2}$ to 153.98$g \cdot cm^{-1} \cdot s^{-2}$. It means a decrease of 7.978% using Eq. (6).

The result values of shear stress (in shear rate $\dot{\gamma}$ = 93 s^{-1}) of automobile engine oil taken from CI engine are seen in Table6 and showed in Fig. 8.

Table 6. Shear stress of engine oil – Oil_2 (CI engine)

Raid, km	Shear stress, $g \cdot cm^{-1} \cdot s^{-2}$
0	139.79
1,475	135.22
2,985	134.67
4,436	131.27
6,060	129.18
7,820	128.19
9,194	127.09
11,253	124.12
13,211	120.04
14,956	117.23

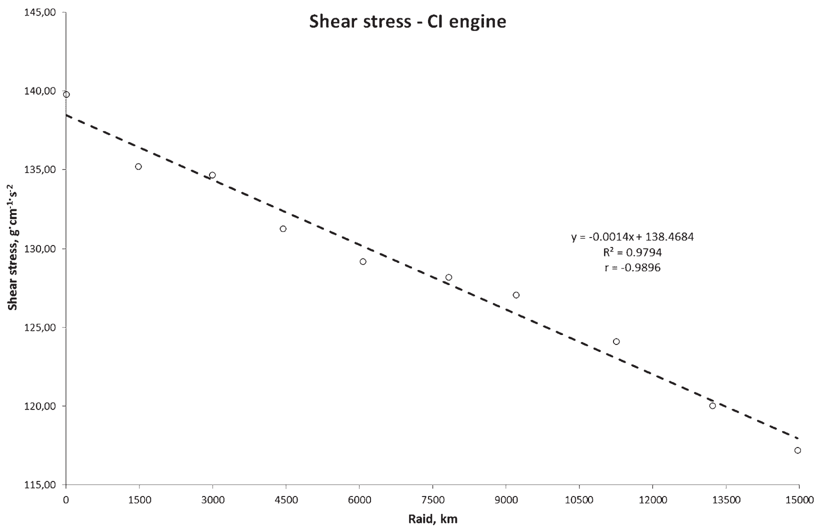

Fig. 8. Shear stress of engine oil – Oil_2 (CI engine)

Result values of shear stress of Oil_1 (taken from SI engine) were modeled using linear function. The general equation of linear function is same as Eq. (3). Equation for counting shear stress of engine oil (SI engine) is:

$$\tau(s) = -0.0014 \cdot s + 138.4684 \left[\mathrm{g} \cdot \mathrm{cm}^{-1} \cdot \mathrm{s}^{-2}; km \right] \quad (10)$$

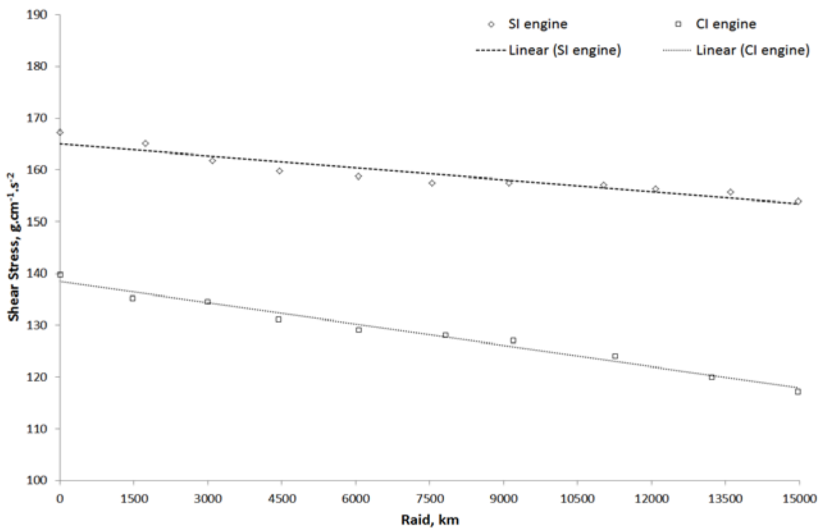

Fig. 9. Shear stress of engine oils– Oil_1 and Oil_2 (SI and CI engine)

where τ is shear stress and s is raid. The absolute value of correlation coefficient, r, is 0.9896 and value of coefficient of determination, R^2, is 0.9794.

For CI engine and Oil_2 we can state:

With increasing count of the kilometers (raid) the shear stress of Oil_2 decreased. The shear stress of Oil_2 (taken from CI engine) decreased from the 139.79g·cm^{-1}·s^{-2}to 117.23g·cm^{-1}·s^{-2}. It means a decrease of 16.138% using Eq. (6).

Fig. 9 is created by way of contrast of shear stress of both engine oils taken from SI and CI engine.

Created mathematical models achieve high accuracy. The obtained trends are descriptive and predict the behaviour of kinematic viscosity and shear stress, especially the dependence on the raid.

4. Conclusion

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 dynamic viscosity, kinematic viscosity, and shear stress of engine oil changes with raid. Two different commercially distributed engine oils were used: engine oil with viscosity class 10W-40 and engine oil with viscosity class 5W-30.Samples of used engine oil were taken from two vehicles–with spark-ignition engine and compression-ignition engine.

We can state that the differences of degradation of engine oils were extensive (in standard interval 15,000 km). For measurement of physical properties state:

- The dynamic viscosity of 10W-40engine oil (taken from SI engine) decreased of **6.911%** and the kinematic viscosity of 5W-30engine oil (taken from CI engine) decreased of **17.418%**.
- The kinematic viscosity of 10W-40engine oil (taken from SI engine) decreased of **6.909%** and the kinematic viscosity of 5W-30engine oil (taken from CI engine) decreased of **17.415%**.
- The shear stress of 10W-40engine oil (taken from SI engine) decreased of **7.978%** and the shear stress of 5W-30engine oil (taken from CI engine) decreased of **16.135%**.

The differences may were caused by addicting rapeseed oil methyl ester (RME) in conventional diesel, higher combustion temperature in CI engine, and higher compression ratio in CI engine.

The result values were modeled using elementary mathematical model – linear function. The absolute values of correlation coefficients, r, were achieved very high values – from 0.9402 to 0.9952. The values of coefficients of determination, R^2, were also achieved very high values – from 0.8840 to 0.9905.

The obtained trends may descriptive and predict the dynamic viscosity, kinematic viscosity, and shear stress, especially the dependence on the raid. The created mathematical models can be used to prediction of engine oil flow behaviour and increased engine reliability.

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References

1. Albertson WC, Staley DR, McDonald MM, Pryor BK. Engine oil viscosity diagnostic system and methods, United States Patent, 20080223114, 2008.
2. Anonymous, On-line fluid condition monitoring technology, Practicing Oil Analysis 2006; 2: 15-21.
3. Barnes HA, Hutton J F, Walters K. AnIntroduction to Rheology. Oxford: Elsevier,1998.
4. Cerny J, Masek P. Change the quality of new filling engine oil. Fuels 2010;2(1): 1-3. (in Czech)
5. Dowson D. Thinning Films and Tribological Interfaces. Published by Elsevier, 2000.
6. Fitch EC. Temperature stability, Machinery Lubrication 2002; 3: 35-39.
7. Khonsari MM. Low temperature and viscosity limits, Machinery Lubrication 2007; 2: 26-31.
8. Kumbar V, Dostal P. Temperature dependence density and kinematic viscosity of petrol, bioethanol and their blends. Pakistan Journal of Agricultural Sciences 2014; 51(1): 175-179.
9. Leugner L. The Practical Handbook of Machinery Lubrication, Published by Maintenance Technology International, 2005.
10. Lewi A, Peew D. On the evaluation of exploitation qualities of PristaSuper 25W40 motor oil with DIA method. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2011; 4: 11-14.
11. Mang T, Dresel W. Lubricants and Lubrication,Weinheim: Wiley-vch,2001.
12. Saleh AA, Hashim E T. Modeling of shear stress and shear strain rate of oil in water emulsions. Petroleum Science and Technology 2009; 27(8): 777-780.
13. Spearot JA. Engine oil viscosity classification low-temperature requirements – current status and future needs,In: Low Temperature Lubricant Rheology Measurement and Relevance to Engine Operation, Philadelphia: ASTM Publication, 1992.
14. Spearot JA. High-Temperature, High-Sheer (HTHS) Oil Viscosity Measurement and Relationship to Engine Operation, Philadelphia: ASTM Publication, 1989.
15. Standard ISO 8217 – Fuel standard, 2000.
16. Standard Test Method for Low Temperature, Low Shear Rate, Viscosity/Temperature Dependence of Lubricating Oils Using a Temperature-Scanning Technique.West Conshohocken: ASTM International, 2005.
17. Stewart R M.The relationship between oil viscosity and engine performance – a literature search,In: The Joint SAE-ASTM Symposium on the Relationship of Engine Oil Viscosity to Engine Performance, Detroit, 1977: 5-24.
18. Takata R, Wong VW. Effects of lubricant viscosity on ring/liner friction in advanced reciprocating engine systems,In: Proceedings of ICEF06 ASME Internal Combustion Engine Division 2006 Fall Technical Conference, Sacramento, 2006:1526-1535.
19. Thibault R. How to read an oil can. Machinery Lubrication 2001; 1: 3-6.
20. Troyer D. Understanding absolute and kinematic viscosity, Practicing Oil Analysis 2002; 1: 15-19.

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