ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 195 Number 6, 2013
http://dx.doi.org/10.11118/actaun201361061763

LOW-TEMPERATURE BEHAVIOUR OF THE ENGINE OIL

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Received: September 16, 2013

Abstract

KUMBÁR VOJTĚCH, SABALIAUSKAS ARTÜRAS: *Low-temperature behaviour of the engine oil.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 6, pp. 1763–1767

The behaviour of engine oil is very important. In this paper has been evaluated temperature dependence kinematic viscosity of engine oils in the low temperatures. Five different commercially distributed engine oils (primarily intended for automobile engines) with viscosity class 0W–40, 5W–40, 10W–40, 15W–40, and 20W–40 have been evaluated. The temperature dependence kinematic viscosity has been observed in the range of temperature from –15 °C to 15 °C (for all oils). Considerable temperature dependence kinematic viscosity was found and demonstrated in case of all samples, which is in accordance with theoretical assumptions and literature data. Mathematical models have been developed and tested. Temperature dependence dynamic viscosity has been modeled using a polynomials 3rd and 4th degree. The proposed models can be used for prediction of flow behaviour of oils. With monitoring and evaluating we can prevent technical and economic losses.

engine oil, low temperature, kinematic viscosity, density, modeling

Engine oil is the oil used for lubrication of various internal combustion engines. While the main function is to lubricate moving parts, motor 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, organic compounds consisting entirely of carbon and hydrogen (Severa *et al.*, 2009).

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 (Stewart, 1977). That is why the first lubricant standard J300 that was developed by SAE in 1911 was Viscosity Classification of Motor Oils, and although this standard was revised and updated many times it is still used today world–wide for Motor Oil applications. Now, the oil's viscosity is identified by its SAE's (Society for Automotive Engineer's) number. The thinner the oil is, lower its number, e.g. SAE 10 W. The numerical relates to 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 temperature. Such oils are called multi–grade oils, for instance '20W–40' shows thinness at low temperature and thickness at higher temperature (Leugner, 2003).

Following general recommendations apply Troyer (2002): SAE viscosity grade motor oil: 5W–30; Temperature conditions: Below –18° C; Description: Provides excellent fuel economy and low temperature performance in most late–model engines. Especially was recommended for new car engines.

Adding anything foreign to the oil can change its viscosity. Some types of aftermarket 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 the oil's viscosity. Exposure to excessive heat (leaving the oil in use too long, engine overheating) can also increase viscosity (Quinchia *et al.*, 2012).

There are several different methods for measuring oil's viscosity. Except traditional methods (such us capillary, falling ball, rotary etc.) – in detail described in Spearot (1989), or Troyer (2002), there are new approaches described eg. in Kumbár *et al.* (2013), or Albertson *et al.* (2008).

MATERIAL AND METHODS

Engine oils

Five different commercially available automobile engine oils were used. Everything oils were of synthetic type. The oil samples were purchased in local distribution network. The description of the oils is given in Tab. I.

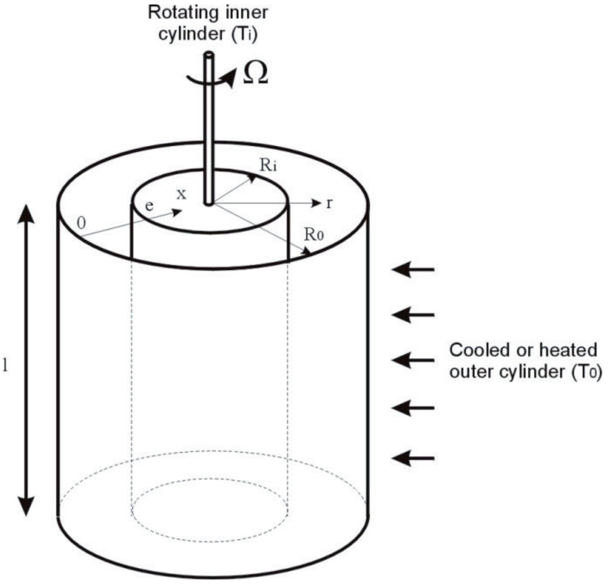
Temperature dependent of dynamic viscosity

The temperature measurements of the kinematic viscosity were determined in the temperature range from −15 °C to 15 °C. The samples were cooled and then slowly heated.

Measuring of temperature dependence of dynamic viscosity of given oils were performed using rotational viscometer Anton Paar DV–3P. This experimental device measures the torque of rotating spindle placed into the sample. The viscometer detects the resistance against rotation of cylinder or disc surrounded by measured fluid. The rotating cylinder or disc is connected with electric motor shaft via defined springs. The shaft is rotating by set speed (expressed in rotations per minute). The angle of swing is electronically monitored and offers the precise information on shaft (spindle) position. The measured data are used for calculation of kinematic viscosity expressed in $m^2.s^{-1}$. In case of fluids with constant viscosity is the resistance against movement increased with spindle size. The range of measuring and rheological properties determination can be customized according to specific measuring and experimental conditions by selection of spindle and its rotation velocity. Relevant evaluation of the results is conditioned by detailed knowledge of tested material. It is necessary to classify the material in a correct way (Kumbár and Polcar, 2012).

I: *Description of samples of oils*

No.	Signification	Viscosity class	Performance class
1	Mobile1 New Life	0W–40	ACEA A3/B3/B4 API SM/CF
2	Carlson Millenium SYNTH	5W–40	ACEA A3/B3/B4 API SJ/CF/EC
3	Castrol Magnatec	10W–40	ACEA A3/B3/B4 API SL/CF
4	MOL Dynamic Gas Eco+	15W–40	ACEA A3/B4/E7 API CI-4/CF/SL
5	Mogul M7ADS III	20W–40	API CF-4/SF



1: *Schematic of the measuring geometry*

The sample oil was measured with use of standard spindle of R3 type, which is the most suitable spindle for this kind of test specification. The spindle speed (rpm) was selected to 20–200 rpm.

In the SI–system the theoretical unit is $m^2.s^{-1}$ or commonly used Stoke (St). Schematic of the measuring geometry is shown in Fig. 1.

The temperature dependence was modeled using polynomials of 3rd and 4th degree.

RESULTS AND DISCUSSION

Temperature dependence kinematic viscosity

The viscosity degradation of engine oils was monitored by measuring and comparing the temperature dependence kinematic viscosity. As expected of authors and in accordance with the publication (Mang and Dresel, 2001) significantly decreased kinematic viscosity with increasing temperature.

Tab. II lists the values of engine oils kinematic viscosity and density at reference temperature 15 °C.

The graph in Fig. 2 shows a decrease of kinematic viscosity of engine oils with increasing temperature.

The graph in Fig. 3 shows the mathematical models using polynomial 3rd and 4th degree, according to general forms:

3rd degree:

$$y(x) = a_3 \times x^3 + a_2 \times x^2 + a_1 \times x + a_0, \quad (1)$$

4th degree:

$$y(x) = a_4 \times x^4 + a_3 \times x^3 + a_2 \times x^2 + a_1 \times x + a_0. \quad (2)$$

For the calculation of kinematic viscosity apply:

3rd degree:

$$v(t) = a_3 \times t^3 + a_2 \times t^2 + a_1 \times t + a_0 \, [\mathrm{m^2 \cdot s^{-1}; ^\circ C}], \quad (3)$$

4th degree:

$$v(t) = a_4 \times t^4 + a_3 \times t^3 + a_2 \times t^2 + a_1 \times t + a_0 \, [\mathrm{m^2 \cdot s^{-1}; ^\circ C}], \quad (4)$$

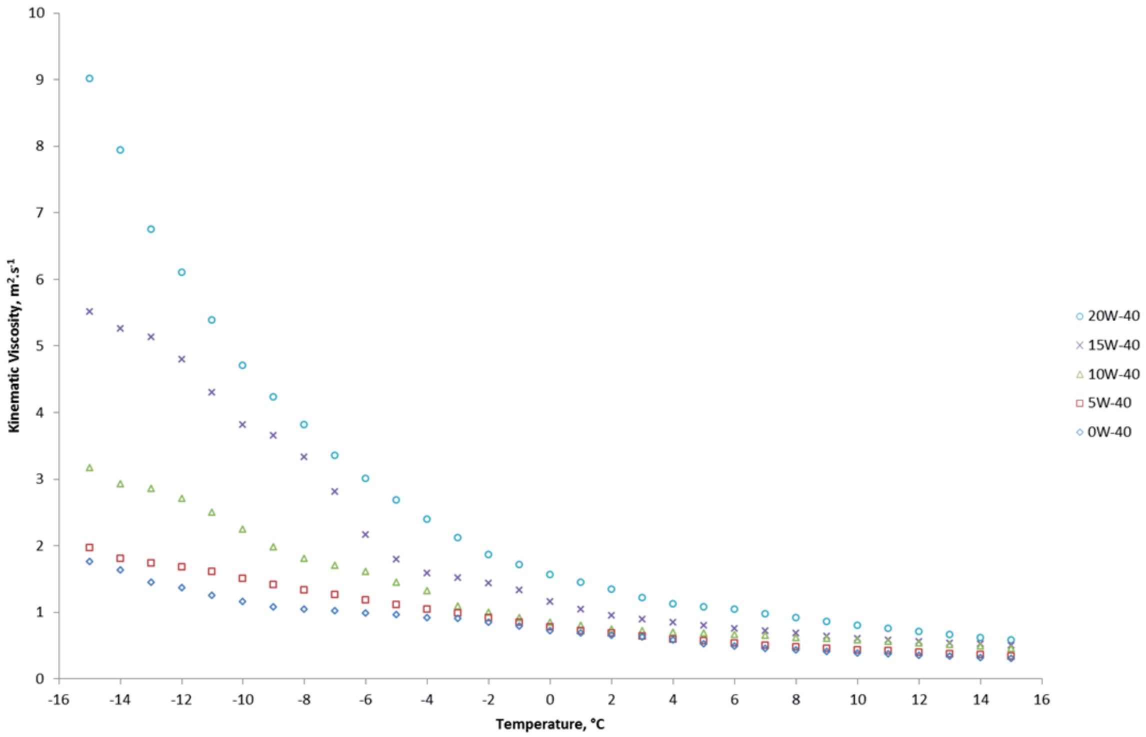
where ν is dynamic viscosity, t is temperature and a_i are constants.

For an accurate calculation of kinematic viscosity (in the temperature range −15 °C to 15 °C) of engine oil, the values of constants given in Tab. III.

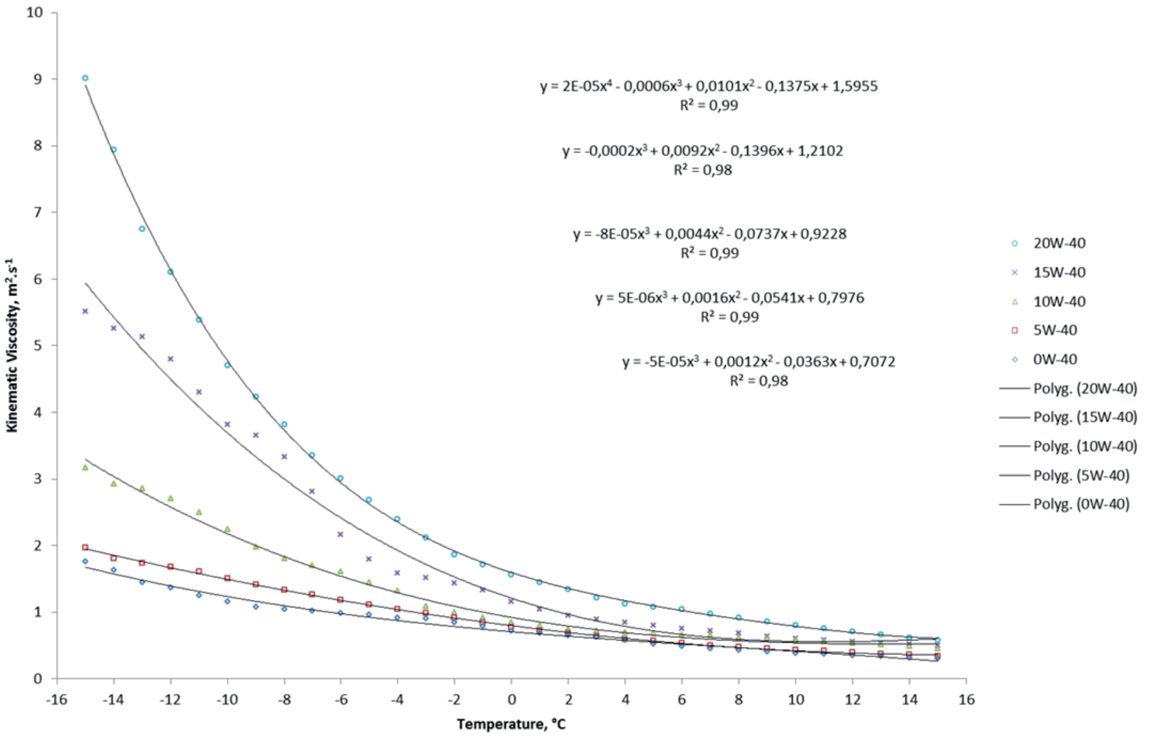
Created mathematical models achieve high accuracy, since the coefficients of determination R^2 ranged from 0.98 to 0.99.

II: *Density and kinematic viscosity at reference temperature 15 °C*

No.	1	2	3	4	5
Density, $kg.m^{-3}$	848	852	857	878	870
Kinematic viscosity, $m^2.s^{-1}$	0.305	0.342	0.452	0.506	0.584



2: *Temperature dependence kinematic viscosity*



3: *Temperature dependence kinematic viscosity with mathematical models*

III: *Values of constants (engine oil)*

No.	a_4	a_3	a_2	a_1	a_0
1	0	–0.00005	0.0012	–0.0363	0.7072
2	0	0.000005	0.0016	–0.0541	0.7976
3	0	–0.00008	0.0044	–0.0737	0.9228
4	0	–0.0002	0.0092	–0.1396	1.2102
5	0.00002	–0.0006	0.0101	–0.1375	1.5955

CONCLUSIONS

Engine oils have been cooled to below zero temperatures and under controlled temperature regulation, kinematic viscosity ($m^2.s^{-1}$) have been measured in the range of the temperatures –15 °C and +15 °C. In accordance with expected behaviour, kinematic viscosity of all oils was decreasing with increasing temperature. The viscosity of oil is highly temperature dependent and for kinematic viscosity value to be meaningful, the reference temperature was chosen as 15 °C. Viscosity value at this reference temperature changed from the 0.305 $m^2.s^{-1}$, to the 0.584 $m^2.s^{-1}$. Kinematic viscosity was found to be independent on oil's density.

Several mathematical models have been used for modeling of oils' temperature dependence. Following matches between experimental computed values have been achieved: $R^2 = 0.98$ and $R^2 = 0.99$ for polynomial fit. Mathematical models for temperature-dependent behaviour of kinematic viscosity of liquid lubricants achieve very high accuracy, which demonstrate a high coefficient of determination R^2 values (0.98–0.99). These models can be used for predicting the viscosity behaviour of liquid lubricants (oils) used in automobile technology.

SUMMARY

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 viscosity of engine oil changes with temperature. Five different commercially distributed engine oils were used: Mobile1 New Life (0W–40), Carlson Millenium SYNTH (5W–40), Castrol Magnatec (10W–40), MOL Dynamic Gas Eco+ (15W–40), Mogul M7ADS III (20W–40). The oils used are primarily intended for automobile engines. Everything engine oils were synthetic. The flow curves have not been

constructed since the fluid was (according to literature results and own measurements) considered to be Newtonian. Due to this fact, no special pretreatment, such as pre–shear, of specimens was necessary.

Engine oils have been cooled to below zero temperatures and under controlled temperature regulation, kinematic viscosity ($m^2.s^{-1}$) have been measured in the range of the temperatures –15 °C and +15 °C. In accordance with expected behaviour, kinematic viscosity of all oils was decreasing with increasing temperature. The viscosity of oil is highly temperature dependent and for kinematic viscosity value to be meaningful, the reference temperature was chosen as 15 °C. Kinematic viscosity value at this reference temperature changed from the 0.305 $m^2.s^{-1}$, to the 0.584 $m^2.s^{-1}$. Kinematic viscosity was found to be independent on oil's density. Several mathematical models have been used for modeling of oils' temperature dependence. Following matches between experimental computed values have been achieved: $R^2 = 0.98$ and $R^2 = 0.99$ for polynomial fit. Mathematical models for temperature-dependent behaviour of kinematic viscosity of liquid lubricants achieve very high accuracy, which demonstrate a high coefficient of determination R^2 values (0.98–0.99).

These models can be used for predicting the viscosity behaviour of liquid lubricants (oils) used in automobile technology. Description of viscosity behaviour of an engine oil as a function of its temperature is of great importance, especially when considering running efficiency and performance of combustion engines. Proposed models can be used for description and prediction of rheological behaviour of engine oils.

Acknowledgement

The research has been supported by the projects IP 22/2012 and the project CZ.1.07/2.3.00/20.0005.

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