ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 14 Number 1, 2013

http://dx.doi.org/10.11118/actaun201361010115

RHEOLOGICAL PROFILES OF BLENDS OF THE NEW AND USED MOTOR OILS

Vojtěch Kumbár, Adam Polcar, Jiří Čupera

Received: September 26, 2012

Abstract

KUMBÁR, VOJTĚCH, POLCAR ADAM, ČUPERA JIŘÍ: *Rheological profiles of blends of the new and used motor oils.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 115–121

The objective of this paper is to find changes of a rheological profile of the new engine oil if the used engine oil will be add. And also find changes of a rheological profile of the used engine oil if the new engine oil will be add. For these experiments has been created the blends of the new and the used engine oil. The temperature dependence of the density [$kg.m^{-3}$] has been measured in the range of −10 °C and +60 °C. The instrument Densito 30PX with the scale for measuring engine oils has been used. The dynamic viscosity [*mPa.s*] has been measured in the range of −10 °C and +100 °C. The Anton Paar digital viscometer with the concentric cylinders geometry has been used. In the accordance with the expected behaviour, the density and the kinematic viscosity of all oils was decreasing with the increasing temperature. To the physical properties has been the mathematical models created. For the temperature dependence of the density has been used the linearly mathematical model and the exponentially mathematical model. For the temperature dependence of the dynamic viscosity has been used the polynomial 6th degree. The knowledge of density and 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.

engine oil, blend, viscosity, density, temperature, modeling

For passenger cars, vans, trucks, construction and agricultural machinery, motorcycles and other vehicles must be changed the engine oil (in the specific intervals). The load of engine oil must be changed after driving about 6,000 km for motorcycles, about 15,000 km for passenger cars and after 200 operating hours of work for agricultural machines. The exception is racking of engine. It always depends on the manufacturer's recommendations.

The first intervention in the life of engine oil is already at an oil change. Usually all old (used) oil it not release from the engine. Always remain a part of the engine oil in the oil sump and in the lubrication system. The remaining part of the old used oil is mixed with the new oil (after filling) and there is interaction with oxidation products of the old oil with the new oil and his additives. The interaction of these substances can lead to changes the quality of the new motor oil, which describes Černý (2010).

If the old oil mixes with the new engine oil, the dynamic viscosity of the new engine oil decrease, which may cause a malfunction of the oil at the low temperatures, as described in Kumbár (2010).

The second case is topping the new engine oil into the oil partially or completely used motor oil. This is mainly done by unprofessional interventions users themselves, who want to extend oil life and thus save their money. This can lead to the irreversible changes in the engine. The degradation of engine oil does not stop by adding a small amount of the new engine oil into the old oil in accordance with the publication Kumbár (2011a). Another thing is topping up the new engine oil if the level falls below the minimum amount of the engine oil filling. This happens mostly during the interval of the engine oil life.

MATERIALS AND METHODS

Blends of engine oil

For monitoring the rheological profiles of the blends of the new engine oil and used engine oil was used Mogul Felicia. The manufacturer describes it as universal year-round oil for the modern petrol and diesel engines. This engine oil is formulated to the Škoda cars. Other properties are given in the Tab. I.

The vehicle, which has been engine oil monitored, was the car Škoda Felicia, 1.3MPI (50 kW), vintage 1999. It was monitored the new engine oil, the used engine oil (mileage 15,000 km) and their blends. A detailed description is in the Tab. II.

Density measurement

The instrument Densito 30PX with the scale for measuring engine oils has been used. This instrument can measure with the high degree of accuracy ±1 kg.m^{-3}. The measurement was doing at the temperature from −10 °C to +60 °C. Sampling was done every 10 °C.

Viscosity measurement

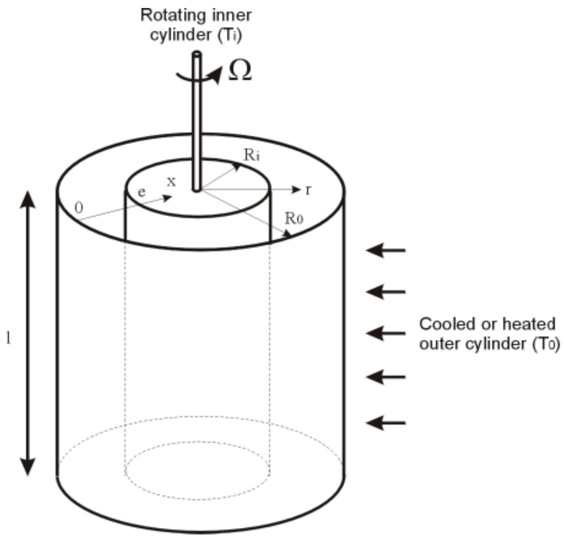
The procedure of sample preparation for viscosity measurements corresponded to a typical sampling procedure. The adequate volume (200 ml) of oil was put into the apparatus cuvette without previous heavy mixing or any other kind of preparation. There are several methods to measure kinematic viscosity 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 viscometer Anton Paar DV–3 P (Austria), which is designed to measure dynamic or kinematic viscosity (η, ν), shear stress (τ), and shear rate ($\dot{\gamma}$). The DV–3 P is a rotational viscometer, based on measuring the torque of a spindle rotating in the sample at a given speed. Shear stress is expressed in [g.cm^{-1}.s^{-2}], shear rate in [s^{-1}], kinematic viscosity in [mm^2.s^{-1}], and speed of spindle in revolutions per minute [rpm]. The experiments have been performed with use of R3 spindle. Due to the parallel cylinder geometry shear stress, 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 it is mass density

$$\nu = \frac{\eta}{\rho}, \quad (1)$$

where
ν...... kinematic viscosity,
η...... absolute of dynamic viscosity,
ρ...... density.

In the SI–system the theoretical unit is m^2.s^{-1} or commonly used Stoke [*St*], Severa (2009).

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



1: *Schematic of the measuring geometry*

The viscosity data were obtained for temperature range −10 °C and +100 °C.

I: *Behaviours of the engine oil MOGUL FELICIA*

Signification	Viscosity class	ACEA standard	API standard	VW standard
MOGUL FELICIA	15W40	A3/B3	SH/CF	501.01/505.00

II: *The description of blends*

Num. of sample	New engine oil		Used engine oil	
	ml	vol. %	ml	vol. %
1	0	0	200	100
2	50	25	150	75
3	100	50	100	50
4	150	75	50	25
5	200	100	0	0

Mathematical models

Mathematical models have been created with use of software Microsoft® Excel 2002 (10.6856.6856) Service Pack 3.

RESULTS AND DISCUSSION

Density

The temperature dependence of the density has been measured for all the blends of the new and used engine oil. For all the blends density declined, if the temperature rise. The decrease has been modelled. The linearly and the exponentially mathematical models have been used as in Kumbár (2011b).

The detailed descriptions are shown in the Tab. III and graphically illustrated in the Fig. 2.

In the graph (in the Fig. 3) has been done the linearly mathematical model for the blend 50_50, where is 50% of the new engine oil and 50% of the used oil. For this model is valid:

The linearly model (the general form):

$$y(x) = ax + k, \quad (2)$$

to calculate the density is valid:

$$\rho(t) = at + k \; [kg.m^{-3};\ ^{\circ}C]. \quad (3)$$

For the 50_50 blend is valid $a = -0.2857$; $k = 879.14$.

In the graph (in Fig. 4) has been done the exponentially mathematical model for the blend 50_50, where is 50% of the new engine oil and 50% of the used oil. For this model is valid:

The exponentially model (the general form):

$$y(x) = ae^{kx} = a.\exp(kx), \quad (4)$$

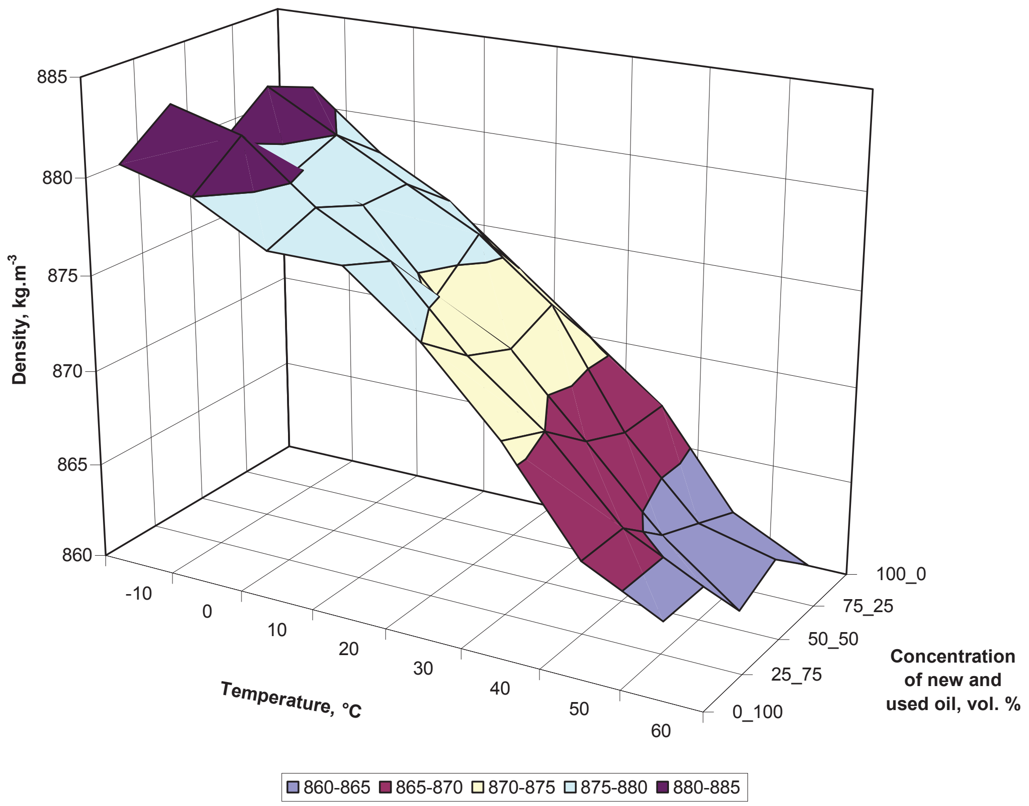
to calculate the density is valid:

$$\rho(t) = ae^{kt} = a.\exp(kt) \; [kg.m^{-3};\ ^{\circ}C]. \quad (5)$$

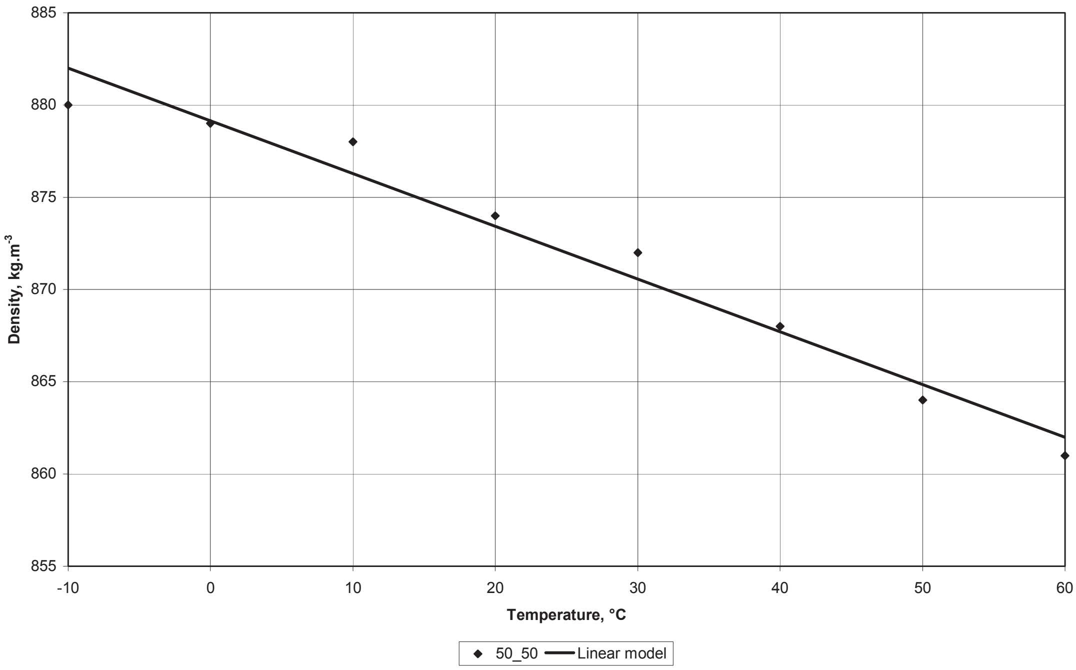
For the 50_50 blend is valid $a = 879.15$; $k = -0.0003$.

III: *The temperature dependence of density*

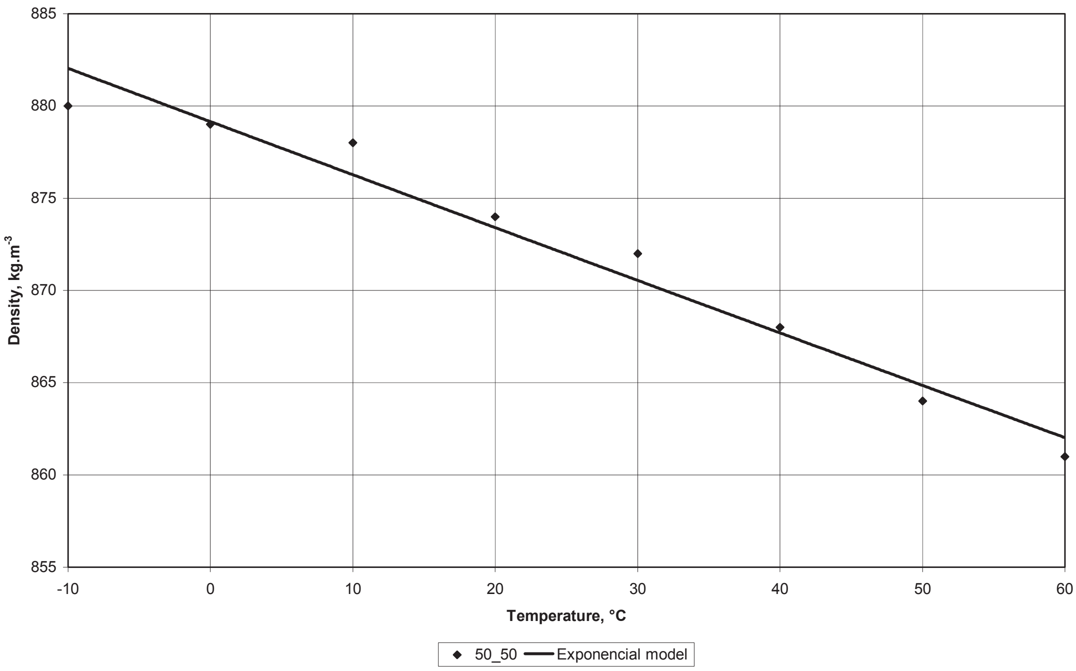
Number of sample	Signature of blend	New oil, *vol. %*	Used oil, *vol. %*	Temperature dependence of density, kg.m⁻³							
				Temperature, °C							
				−10	0	10	20	30	40	50	60
1	0_100	0%	100%	881	880	878	878	875	871	866	864
2	25_75	25%	75%	883	882	879	877	873	870	866	864
3	50_50	50%	50%	880	879	878	874	872	868	864	861
4	75_25	75%	25%	882	880	878	876	873	867	863	862
5	100_0	100%	0%	881	878	876	873	870	867	862	858



2: *Three-dimensional graph of the temperature dependence of the density*



3: *The linearly mathematical model*



4: *The exponentially mathematical model*

IV: *Comparison of the coefficients*

	Linear model	Exponential model
Signature of blend	**Correlation coefficient** R	**Coefficient of determination** R^2
0_100	0.928	0.928
25_75	0.986	0.985
50_50	0.969	0.968
75_25	0.966	0.965
100_0	0.985	0.984

In Tab. IV is shown a comparison of the coefficients of correlation *R* (the linearly model) and determination R^2 (the exponentially model) for all blends of the new and used engine oil.

Both use the coefficients reached the high values – from 0.928 to 0.986 for the linearly model and from 0.928 to 0.985 for the exponentially model. For the individual blends of the new and used engine oil are not high differences in the coefficients in dependence of the used mathematical model.

Viscosity

The temperature dependence of dynamic viscosity has been measured for all blends of the new and used engine oil. For all blends dynamic viscosity declined, if the temperature rise. The decrease has been modelled. The polynomial (6th degree) mathematical model has been used as in Pramanic (2003) and Maggi (2006). The graphically illustrated is shown in the Fig. 5.

In Fig. 6 has been done the polynomial (6th degree) mathematical model for the blend 50_50, where is 50% of the new engine oil and 50% of the used oil. For this model is valid:

The polynomial 6th degree (the general form):

$$y(x) = a_6x^6 + a_5x^5 + a_4x^4 + a_3x^3 + a_2x^2 + a_1x + a_0, \quad (6)$$

to calculate the dynamic viscosity is valid:

$$\eta(t) = a_6t^6 + a_5t^5 + a_4t^4 + a_3t^3 + a_2t^2 + a_1t + a_0 \; [mPa.s], \quad (7)$$

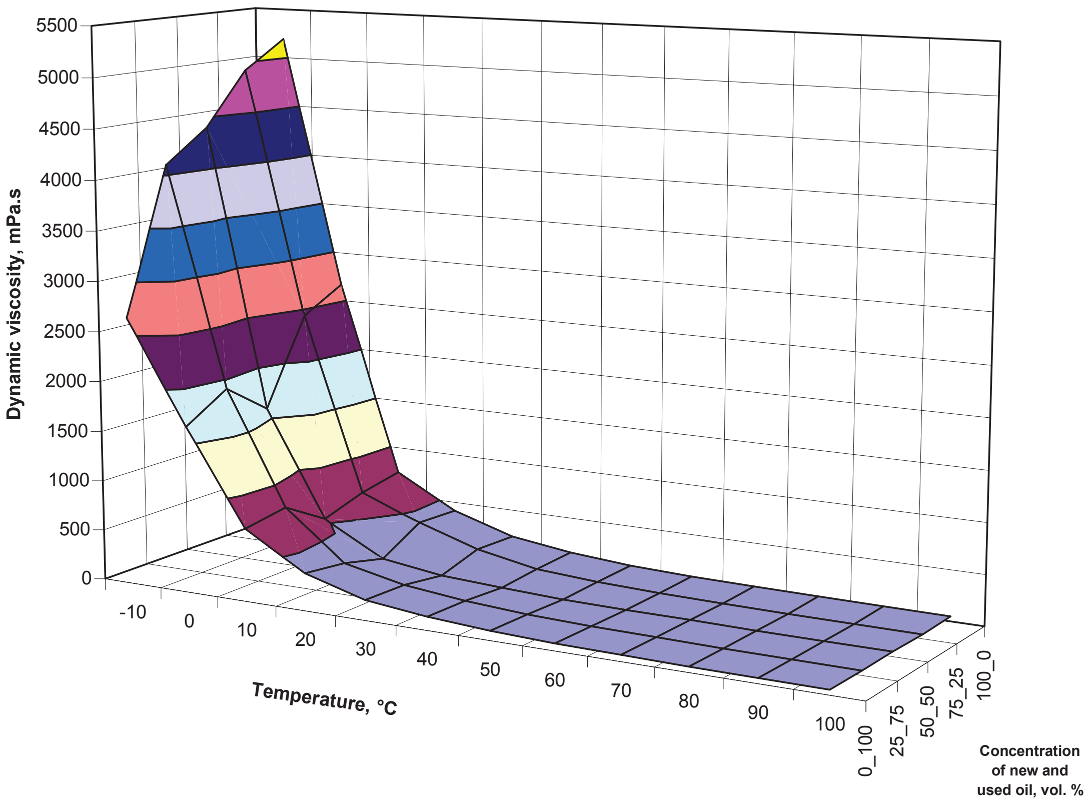
for the blend 50_50 is valid $a_0 = 1{,}484.8$; $a_1 = -213.64$; $a_2 = 14.461$; $a_3 = -0.4809$; $a_4 = 0.0081$; $a_5 = -7\times10^{-5}$; $a_6 = 2\times10^{-7}$.

In Tab. V is shown the comparison of the determination coefficients R^2 (the exponentially model) for all blends of the new and used engine oil.

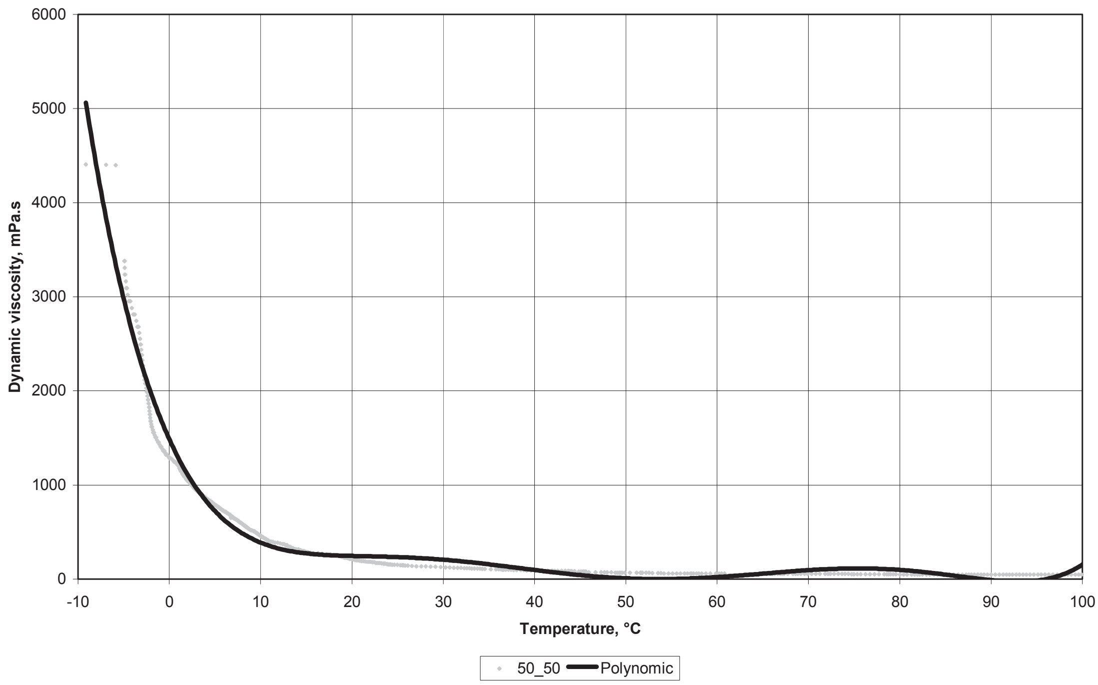
The coefficients of determination reached high values – from 0.971 to 0.990 for the polynomial (6th degree) mathematical model.

CONCLUSIONS

The density and the dynamic viscosity have been showed the significant temperature dependence. If the temperature increased, the density and dynamic viscosity decreased. Similar results have been confirmed in their publications Mang (2001), Guo (2007) and Albertson (2008). The density decreased from an average of the 881 kg.m^{-3} at –10 °C to an average of the 862 kg.m^{-3} at +60 °C for all blends of the new and used engine oils. This decrease was almost linear. The correlation coefficient R values ranged 0.93 to 0.99 (for the linear model) for the blends of the new and used engine oils. The values of the correlation coefficient R and the determination coefficient R^2 were almost the same. The dependence of density on the duration of use of the engine oil has not been established. The dynamic viscosity decreased from an average of the 4,256 *mPa.s* at –10 °C to an average of the 124 *mPa.s* at +40 °C and to an average of the 46 *mPa.s* at +100 °C for all blends



5: *Three-dimensional graph of the temperature dependence of the dynamic viscosity*



6: *The polynomial (6th degree) model*

V: *Comparison of the coefficients of determination*

	Polynomial model (6th degree)
Signature of blend	**Coefficient of determination R^2**
0_100	0.969
25_75	0.990
50_50	0.976
75_25	0.971
100_0	0.972

of the new and used engine oils. The temperature dependence of dynamic viscosity has been modelled by the polynomial mathematical model as in Severa (2008). The values of the determination coefficient R^2 ranged 0.97 to 0.99. The dependence of dynamic viscosity on the duration of use of the engine oil has been established as in Severa (2009) and (2010) and Kumbár (2011c). After the mileage 15,000 km and at −10 °C decreased the dynamic viscosity from the 5,191 *mPa.s* to the 2,665 *mPa.s*. Over the temperature 20 °C the difference was minimal.

SUMMARY

The objective of this paper is to find changes of the rheological profile of the new engine oil if the used engine oil will be add. And also find changes of the rheological profile of the used engine oil if the new engine oil will be add. The first intervention in the life of the engine oil is already at an oil change. From the engine cannot launch all old oil. Always remain a part of the engine oil in the oil sump and in the lubrication system. The remaining part of the old used oil is mixed with the new oil (after filling) and there is interaction with oxidation products of the old oil with the new oil and his additives. The interaction of these substances can lead to changes the quality of the new motor oil, which describes. If the old oil mixes with the new engine oil, the dynamic viscosity of the new engine oil decrease, which may cause a malfunction of the oil at the low temperatures. The second case is topping the new engine oil into the oil partially or completely used motor oil. This is mainly done by unprofessional interventions users themselves, who want to extend oil life and thus save their money. This can lead to the irreversible changes in the engine. For these experiments has been created the blends of the new and used engine oil. The temperature dependence of the density [kg.m^{-3}] has been measured in the range of −10 °C and +60 °C. The instrument Densito 30PX with the scale for measuring the engine oils has been used. The dynamic viscosity [mPa.s] has been measured in the range of −10 °C and +100 °C. The Anton Paar digital viscometer with the concentric cylinders geometry has been used. To the physical properties has been the mathematical models created. The density and the dynamic viscosity have been showed the significant temperature dependence. If the temperature increased, the density and the dynamic viscosity decreased. The density decreased from an average of the 881 kg.m^{-3} at −10 °C to an average of the 862 kg.m^{-3} at +60 °C. This decrease was almost linear. The

correlation coefficient *R* values ranged 0.93 to 0.99 (for the linear model). The values of the correlation coefficient *R* and the determination coefficient R^2 were almost the same. The dependence of density on the duration of use of the engine oil has not been established. The dynamic viscosity decreased from an average of the 4,256 *mPa.s* at −10 °C to an average of the 124 *mPa.s* at +40 °C and to an average of the 46 *mPa.s* at +100 °C. The temperature dependence of the dynamic viscosity has been modelled by the polynomial mathematical model. The values of the determination coefficient R^2 ranged 0.97 to 0.99. The dependence of the dynamic viscosity on the duration of use of the engine oil has been established. After the mileage 15,000 *km* and at −10 °C decreased the dynamic viscosity from the 5,191 *mPa.s* to the 2,665 *mPa.s*. Over the temperature 20 °C the difference of the dynamic viscosity was minimal. Knowledge of the density and 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 project IP 14/2011 "Degradace motorového oleje používaného v zemědělské technice", and the project TP 1/2011 "Monitorování výkonových parametrů traktorového motoru", both financed by IGA AF MENDELU.

REFERENCES

ALBERTSON, W. C., STALEY, D. R., MC DONALD, M. M., PRYOR, B. K., 2008: *Engine oil viscosity diagnostic system and methods*. United States Patent 20080223114.

ČERNÝ, J., MAŠEK, P, 2010: Změna kvality nových náplní motorového oleje. *Paliva*, 2, 1: 1–3. ISSN 1804-2058.

GUO, B., LYONS, W., GHALAMBOR, A., 2007: *Petroleum production engineering*. United Kingdom: Elsevier Science and Technology Books, 288 s. ISBN 0-7506-8270-1.

KUMBÁR, V., SEVERA, L., HAVLÍČEK, M., 2010: Teplotní závislost nových a použitých olejů. In: *MendelNet 2010 Proceedings of International Ph.D. Student's Conference*. 576–592. ISBN 978-80-7375-453-2.

KUMBÁR, V., GLOS, J., ČORŇÁK, Š., SEVERA, L., HAVLÍČEK, M., 2011a: Hodnocení stavu motoru traktoru New Holland T8040 pomocí analýzy motorového oleje. In: *XIII. Mezinárodní vědecká konference mladých 2011*. 1. vyd. 116–121. ISBN 978-80-213-2194-6.

KUMBÁR, V., ČUPERA, J., HAVLÍČEK, M., SEVERA, L., 2011b: Vliv koncentrace bionafty na její tokové chování. In: *Kvalita a spoľahlivosť technických systémov*. 1. vyd. 198–203. ISBN 978-80-552-0595-3.

KUMBÁR, V., SEVERA, L., GLOS, J., ČORŇÁK, Š., 2011c: *Effect of using additives on increasing of engine oil service life*. In: *Deterioration, Dependability, Diagnostics*. 1. vyd. Brno: University of Defence Brno, 227–234. ISBN 978-80-260-0633-6.

MAGGI, C. P., 2006: Advantages of Kinematic Viscosity Measurement in Used Oil Analysis. *Practicing Oil Analysis Magazine*, 5: 38–52. ISSN 1536-3937.

MANG, T., DRESEL, W., 2001: *Lubricants and Lubrication*. 1. vyd. Weinheim: Wiley-vch, 759 s. ISBN 978-3-527-31497-3.

PRAMANIC, K., 2003: Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. *Renewable Energy*, 28: 239–248. ISSN 0960-1481.

SEVERA, L., LOS, J, 2008: On the influence of temperature on dynamic viscosity of dark beer. *Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis*. 56, 2: 303–307. ISSN 1211-8516.

SEVERA, L., HAVLÍČEK, M., KUMBÁR, V., 2009: Temperature dependent kinematic viscosity of different types of engine oil. *Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis*. 57, 4: 95–102. ISSN 1211-8516.

SEVERA, L., HAVLÍČEK, M., ČUPERA, J., 2010: Changes of engine oil flow properties during its life cycle. *Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis*. 58, 4: 203–208. ISSN 1211-8516.

Address

Ing. Vojtěch Kumbár, Ing. Adam Polcar, Ing. Jiří Čupera, Ph.D., Department of Energineering and Automobile Transport, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, e-mail: vojtech.kumbar@mendelu.cz