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Thermal Conductivity and Dynamic Viscosity of Biooil Samples

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Abstract: *The article deals with thermal and rheologic properties of selected biooils samples. For thermal parameters measurements was used instrument Isomet 2104 and for detection of rheologic parameters was used rheometer Anton Paar MCR 102. For both biooil samples were made two series of thermophysical parameters measurements. In the first series were measured thermal conductivity and thermal diffusivity at constant laboratory temperature. The second series was focused on identification of thermophysical parameters changes during temperature stabilisation. Dynamic viscosity of samples was measured in temperature range (20 - 50) °C. For relations of thermal and rheologic parameters to temperature were obtained nonlinear dependencies.*

Key words: *thermal conductivity, dynamic viscosity, temperature, biooil*

INTRODUCTION

The physical parameters are significant characteristics which can be used for improving of the technologic processes, processing of materials and their storage conditions. Knowledge of physical properties of biooils has a decisive importance for the realization of many technological processes, especially for monitoring of their duality. For quality detection is necessary to know physical and chemical properties of biooils. Dependencies between rheologic parameters were measured by Kumbár – Dostál, (2014). Thermophysical properties of selected types of biooils are presented in literature Božiková - Hlaváč, (2010). Chemical and physical properties of bio-oils were examined by Lu et al., (2008). Based on previous facts this article deals with selected biooils physical properties as:thermal conductivity and dynamic viscosity. There are presented methods and their theoretical principles as well as results of measurements for two biooil samples - Plantohyd 46S – sample № 1 and Plantohyd 40N - sample № 2.

MATERIALS AND METHODS

The chemical composition of bio-oils is very complex. Bio-oils are mainly composed of water, organics and a small amount of ash. According to Meir (1999), these materials can be globally represented as: around 20 % water, around 40 % GC-detectable compounds, around 15 % non-volatile HPLC detectable compounds and around 15 mass% high molar mass non-detectable compounds. A complete analysis of bio-oils requires the combined use of more than one analytical technique. A precise description of bio-oil composition has not yet been achieved. The accuracy of some of these analytical techniques has been highlighted in Round Robin tests Oasmaa – Meier, (2000) conducted by different laboratories. But it is necessary to know also way of biooil usage. Because according physical and chemical parameters is chosen the way of usage.

In our case were examined biooils samples - Plantohyd 46S – sample № 1 and Plantohyd 40N - sample № 2 with these technical characteristics:

- Plantohyd 46 S is a synthetic, rapidly biodegradable fluid based on sustainable raw materials. It is exceptionally suitable for applications in mobile and stationary hydraulic systems, for which a rapidly biodegradable hydraulic oil according to VDMA 24 568, HEES is recommended, especially if there is an environmental hazard to the ground, ground water or the surface waters due to leakage (construction, water resources management, agriculture, forestry).

- Plantohyd 40 N is environmentally friendly multigrade hydraulic oil based on rapeseed oil (HETG) for agricultural and construction machinery, meeting all requirements in accordance with VDMA 24568. With respect to its viscosity position, PLANTOHYD 40N belongs to engine oil SAE class 5W-20 and is recommended for hydraulic systems that require the use of SAE 5W, SAE 10W, SAE 15W, SAE 20W, SAE 20W-20 engine oils or hydraulic oils in accordance with ISO VG 32, VG 46, VG 68 (Fuchs Plantohyd, 2014).

Thermal conductivity was measured by instrument Isomet 2104. The measurement is based on analysis of the temperature response of the analyzed material to heat flow impulses. Heat flow is excited by electrical heating of resistor heater inserted into the probe which is in direct heat contact with the tested specimen. Evaluation of thermal conductivity and volume heat capacity is based on periodically sampled temperature records as function of time, provided that heat propagation occurs in unlimited medium. For thermal conductivity measurements was used needle probe which is convenient for liquid materials. Theoretical description of measurement method for needle probe is the same as for HW (Hot wire) method because needle probe contains the hot wire. The HW method is a transient dynamic technique based on the measurement of the temperature rise of a linear heat source (hot wire) embedded in the tested material (Assael – Antoniadis - Wu, 2008; Kadjo – Garnier – Maye – Martemianov, 2008).

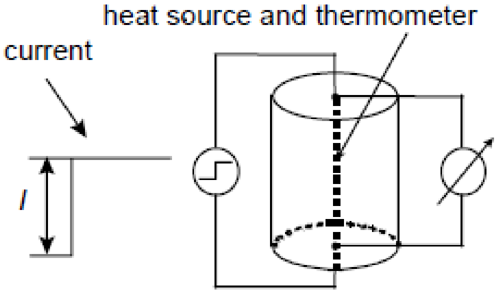


Fig. 1 Hot wire method (Božiková – Hlaváč, 2010)

For an infinitely long metallic wire (length/radius ratio >>200) heated at time t > 0 with a constant heat flux per length unit *q* and immersed in an infinite homogeneous medium (thermal conductivity and diffusivity: λ and a with uniform initial temperature, the temperature rise $\Delta T(t)$ of the wire is given by Eq. (1):

$$\Delta T(t) = \frac{q}{4\pi\lambda} \ln \frac{4F_0}{C} \tag{1}$$

with $C = e^{\gamma} = 1.781$ where γ is Euler's constant ($\gamma = 0.5772$) and *Fo* the Fourier number defined by Eq. (2)

$$F_0 = \frac{a\,t}{r_0^2} \tag{2}$$

Equation (74) is the analytical solution of an ideal thermal conductive model valid for F_0 >>1 nd without convective transfers (Wakeham - Nagashima, 1991). From this ideal model and with known *q* values, the thermal conductivity can be calculated by Eq. (3)

$$\lambda = \frac{q}{4\pi}\left(\frac{dT}{d(\ln t)}\right)^{-1} \tag{3}$$

Where $dT/d(\ln t)$ is a numerical constant deduced from experimental data for t values which satisfy the condition F_0 >>1. For practical applications of the HW method, wire and material sample dimensions, among other ideal model hypothesis, are finite and the deviations from the ideal model have then to be evaluated (Tavman, 1996).

Dynamic viscosity was measured by rheometer Anton Paar MCR 102. The MCR rheometer could be used for basic rheologic parameters measurements and also for combination of rheological tests in rotational and oscillatory mode. The modularity of this system allows the integration of a wide range of temperature devices and application of specific accessories. The temperature measurement range is from -150 °C to +1 000 °C, the maximum torque is 200 mN.m, minimum torque rotation is 5 nN.m, angular velocity is from 10^{-8} rad.s^{-1} to 314 rad.s^{-1}, angular frequency is from the range (10^{-7} – 628) rad.s^{-1} and normal force range is (0.01 - 50) N.

RESULTS AND DISCUSSION

For two samples of biooils – Plantohyd 46 S and Plantohyd 40N was determined basic thermophysical parameter - thermal conductivity by HW method which is described in the previous text. For each biooil sample were made two series of measurements. In the first series was measured thermal conductivity with constant temperature, which was the same as the room temperature 20 °C. Thermal stabilization of the samples was carried out 24 hours before the actual measurement. Thermal conductivity was measured 10 times for each sample.

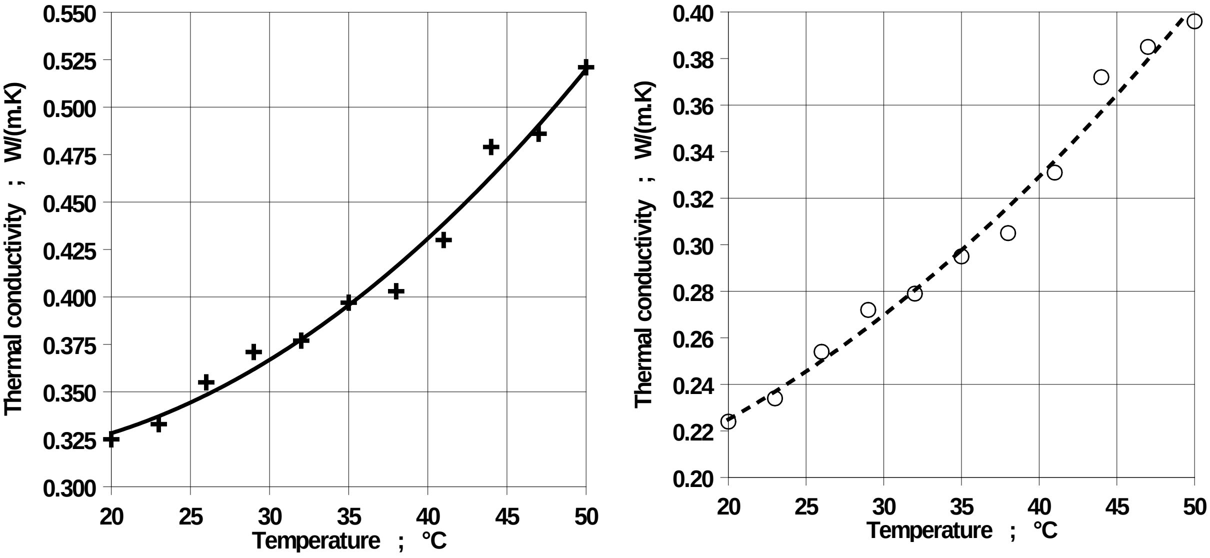
Table 1 Summarisation of results for thermal conductivity measuremets

Statistical evaluation of the measured values for thermal conductivity at 20 °C		
	Sample–biooil № 1	Sample–biooil № 2
The arithmetic average	0.325 W.m^{-1}.K^{-1}	0.224 W.m^{-1}.K^{-1}
Standard deviation	± 0.056 W.m^{-1}.K^{-1}	± 0.054 W.m^{-1}.K^{-1}
Probable error	± 0.012 W.m^{-1}.K^{-1}	± 0.005 W.m^{-1}.K^{-1}
Relative probable error in %	± 3.69 %	± 2.23 %
Statistical evaluation of thermal conductivity graphical dependencies for temperature range (20 - 50) ° C		
Type of function	Polynomial function of the 2^{nd} degree	
The arithmetic average of values λ	0.3956 W.m^{-1}.K^{-1}	0.1965 W.m^{-1}.K^{-1}
Minimum value	0.325 W.m^{-1}.K^{-1}	0.182 W.m^{-1}.K^{-1}
Maximum value	0.486 W.m^{-1}.K^{-1}	0.224 W.m^{-1}.K^{-1}
Polynomial Coefficients		
degree 0	0.599364	0.2951
degree 1	- 0.0353175	0.224
degree 2	0.599364	0.385
Coefficient of Determination - R^2		
degree 0	0	0
degree 1	0.953922	0.953274
degree 2	0.976312	0.987542

The results were statistically processed. There were calculated arithmetic averages of thermal conductivity. For biooil № 1 thermal conductivity was 0.325 W.m^{-1}.K^{-1}, it was higher value than we obtained for biooil № 2 - 0.224 W.m^{-1}.K^{-1}. For samples with constant temperature were calculated basic statistical characteristics as: standard deviation for λ - biooil № 1 (± 0.056 W.m^{-1}.K^{-1}) and biooil № 2 (± 0.054 W.m^{-1}.K^{-1}); probable error of the arithmetic average for λ - biooil №1 (± 0.012 W.m^{-1}.K^{-1}) and biooil №2 (± 0.005 W.m^{-1}.K^{-1});

relative probable error in % for λ - biooil № 1 (± 3.69 %) and biooil № 2 (± 2.23 %). The summary of all statistical characteristics is showed in the table 1.

In the second series of measurements was measured relation of thermal conductivity to the temperature in temperature range (20 - 50) °C. Results are showed on figures 2 and 3. The statistical evaluations of thermal conductivity graphical dependencies are presented in the second part of table 1. From presented results is evident that all measured dependencies are nonlinear. For thermal conductivity were obtained polynomial functions of the second degree with polynomial coefficients and coefficients of determination summarised in table 1. We selected second degree polynomial function as optimal variant for graphic relations because of the highest coefficients determination values. In all cases, were obtained relatively high coefficients of determination in excess of the relevant value 0.95.



a) sample of biooil - Plantohyd 46S b) sample of biooil - Plantohyd 40N

Fig. 2 Relations of thermal conductivity to the temperature

Rheologic parameter - dynamic viscosity was measured in the same temperature range as thermal conductivity. For dynamic viscosity were obtained exponential decreasing relations (Fig. 3) in measured temperature range (20 - 50) °C , which is in accordance with Arrhenius equation presented in literature Božiková at al. (2010). Graphical relations shown on Figure 3 can be characterized by following regression equation (4):

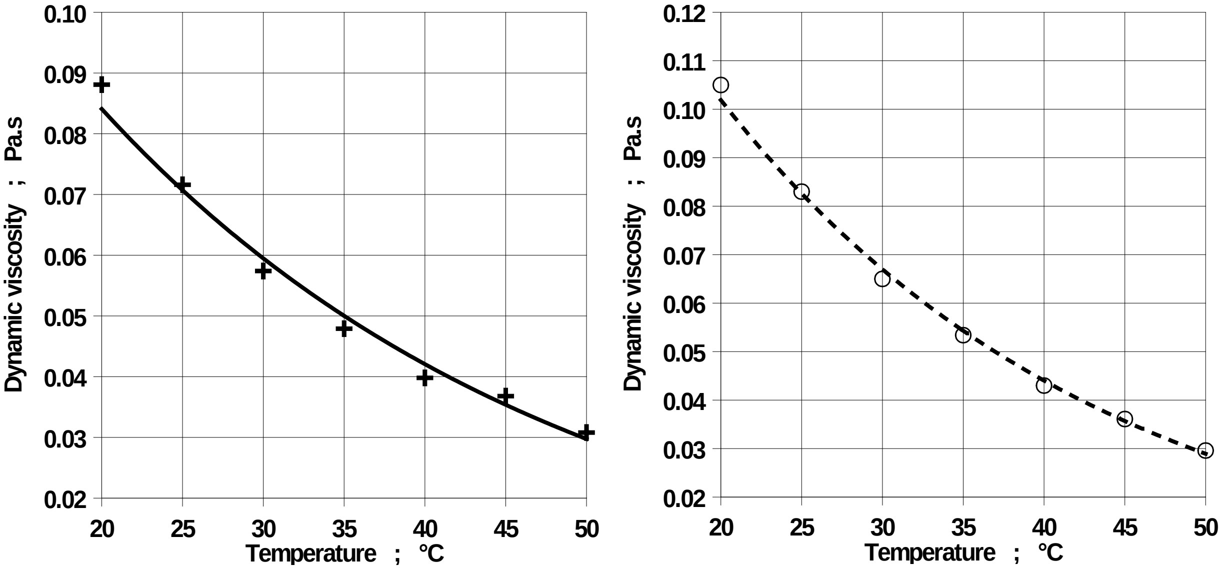
$$\eta = A\, e^{-B\left(\frac{t}{t_0}\right)}, \tag{4}$$

where: A, B constants dependent on material, its composition and ways of processing; t – is temperature (°C); $t_0 = 1°C$.

Table 2 Measurement results for dynamic viscosity

sample	№ 1	№ 2
Regression Coefficients		
A (Pa.s)	0.23593	0.16814
B (1)	0.04198	0.03465
Coefficient of Determination - R^2		
R^2	0.99734	0.98676

The measured and calculated values of biooils rheologic parameters confirmed differences between both samples. The synthetic biooil – № 1 had higher values of dynamic viscosity than second sample, but the differences were higher at lower temperatures (20 - 35) °C and almost the same for higher temperature (43 - 50) °C which is in accordance with hydraulic biooil technical and operational requirements. The coefficients of regression equations and coefficients of determination are presented in Table 2.



a) sample of biooil - Plantohyd 46S b) sample of biooil - Plantohyd 40N

Fig. 3 Relations of dynamic viscosity to the temperature

CONCLUSION

Nowadays we know many types of biooils which differ in its composition, consistency and its physical properties too. The biooil physical parameters were examined by many authors e.g. Zhang et al. (2009), Ren et al. (2013), Wan Nik et al. (2005) etc. They detected changes of biooil´s physical parameters with chemical composition changes. But our research was focused on identification of other parameters which are necessary at defining of material’s state. In generally presented results showed that the biooil quality is not possible to describe by one type of physical parameter because important changes could be observed in other type of physical parameters. In our case the significant changes were determined for thermophysical and rheologic parameters. Based on presented facts is clear that physical research applied on bio-based materials used in industry is very important because materials like biooils go through the thermal manipulation during processing to final products, storage and usage.

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REFERENCES

[1] Assael, M. J., K. D. Antoniadis, J. Wu, 2008. New measurements of the thermal conductivity of PMMA, BK7, and Pyrex 7740 up to 450 K. In International Journal of Thermophysics, vol. 29, 4, p. 1257–1266.

[2] Božiková, M., P. Hlaváč, 2010. Selected physical properties of agricultural and food products – Scientific monograph. 1st ed. SUA in Nitra, Slovakia.

[3] Fuchs Plantohyd , 2014. [online] Fuchs, Germany: Actualised: 2014 [cit. 15. 6. 2015]. URL: <http://www.opieoils.co.uk/p-6377-fuchs-plantohyd-40n-hydraulic-oil.asp>

[4] Kadjo A., J. P. Garnier, J. P.Maye, S. Martemianov, A new transient two-wire method for measuring the thermal diffusivity of electrically conducting and highly corrosive liquids using small samples. In International Journal of Thermophysics, vol. 29, 4, p. 1267–1277.

[5] Kumbár, V., P. Dostál, 2014. Temperature dependence density and kinematic viscosity of petrol, bioethanol and their blends. Pak. J. Agri. Sci. 51 (1): 175-179.

[6] Meir, D. 1999. New Methods for chemical and physical characterization and round robin trstiny. A. Bridgwater (Ed.), *et al.*, Fast pyrolysis of biomass: a handbook, CPL Press, Newbury, UK (1999), pp. 92–101

[7] Oasmaa A., D. Meier, Subject group: analysis and characterization. PyNe workshop Birmingham, UK, 2–4 December 2000.

[8] Ren X., J. Meng, A.M. Moore, J. Chang, J. Gou, S. Park. 2014. Thermogravimetric investigation on the degradation properties and combustion performance of bio-oils. Bior. Tech. Elsevier Science Pub. Co., England. 152: 267-274.

[9] Tavman I. H., 1996. Effective thermal conductivity of granular porous materials. In International Communications in Heat and Mass Transfer, vol. 23, 2, p. 169–176.

[10] Wakeham W. A., A. Nagashima, V. J. Sengers, 1991. Measurement of the transport properties of fluids In Experimental Thermodynamics, vol. 3, Blackwell Scientific Publications, London, UK, 1991.

[11] Wan Nik W. B., F. N. Ani, H. H. Masjuki, S. G. Eng Giap, 2005. Rheology of bio-edible oils according to several rheological models and its potential as hydraulic fluid. Ind. Crop. and Prod. 22 (3): 249 – 255.

[12] Zhang, R., Z. Zhong, Y. Huang, 2009. Combustion characteristics and kinetics of bio-oil. Front. Chem. Eng. China. 3(2): 119 – 124.

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