Selected thermal parameters of bioethanol samples

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Abstract: *This article deals with thermal properties of selected bioethanol samples. Ethanol (CH_3CH_2OH) is a clear liquid. Also known as ethyl alcohol, grain alcohol, and EtOH, the molecules in this fuel contain a hydroxyl group (OH -) bonded to a carbon atom. Ethanol is made of the same chemical compound regardless of whether it is produced from starch and sugar-based feedstocks, such as corn grain, sugar cane etc. For thermal parameters measurements was used hot wire method. The experiment is based on measuring of the temperature rise vs. time evaluation of an electrically heated wire embedded in the tested material. The thermal conductivity is derived from the resulting change in temperature over a known time interval. For two samples of bioethanol were determined basic thermophysical parameters - thermal conductivity and thermal diffusivity. For each bioethanol sample were made two series of measurements. In the first series were measured thermal conductivity and thermal diffusivity at constant room temperature 20 °C. Every thermophysical parameter was measured 10 times for each sample. The results were statistically processed. In the second series of measurements were measured relations of thermal conductivity and thermal diffusivity to the temperature in temperature range (20 - 29) °C. From results was evident that all measured dependencies are nonlinear. For both thermophysical parameters were obtained polynomial functions described by the polynomial coefficients. Type of function was selected according to statistical evaluation based on the coefficient of determination for every thermophysical parameter graphical dependency. All obtained results are presented on figures 1 and 2 and in the tables 1, 2. The results of thermophysical parameters measurements of bioethanol were compared with the values λ and a presented in the literature.*

Keywords: *temperature, thermal conductivity, thermal diffusivity, bioethanol*

INTRODUCTION

Thermal conductivity and thermal diffusivity are properties that characterize the heat transfer behaviour and many times the quality of the finished product depends on the correct setting of the temperature, respectively time course of temperature. Accurate values of these properties are critical for practical design as well as theoretical studies and analysis, especially in the fields of heat transfer and thermal processing (Božiková – Hlaváč, 2010). The knowledge of thermophysical properties of the materials are especially significant in the context of bio-based materials, which are often mechanically or thermally processed respectively for material which are exposed to natural changes of temperature conditions. Due to the previous reasons, the presented contribution deals with the measurement of bioethanol thermal parameters, because bioethanol is material with biological origin.

MATERIALS AND METHODS

The principle fuel used as a petrol substitute for road transport vehicles is bioethanol. Bioethanol fuel is mainly produced by the sugar fermentation process, although it can also be manufactured by the chemical process of reacting ethylene with steam. The main sources of sugar required to produce ethanol come from fuel or energy crops. These crops are grown specifically for energy use and include corn, maize and wheat crops, waste straw, willow and popular trees, sawdust, reed canary grass, cord grasses, artichoke, myscanthus and sorghum plants. There is also ongoing research and development into the use of municipal solid wastes to produce ethanol fuel. Ethanol or ethyl alcohol (C_2H_5OH) is a clear colourless liquid; it is biodegradable, low in toxicity and causes little environmental pollution when spilt. Ethanol burns to produce carbon dioxide and water. Ethanol is a high octane fuel and has replaced lead as an octane enhancer in petrol. By blending ethanol with gasoline we can also oxygenate the fuel mixture so it burns more completely and reduces polluting emissions. Ethanol fuel blends are widely sold in the United States. The most common blend is 10 % ethanol and 90 % petrol (E10). Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected also. Only flexible fuel vehicles can run on up to 85 % ethanol and 15 % petrol blends (E85) (Bioethanol, 2013).

Measuring of thermal parameters was performed by simplified transient Hot Wire (HW) technique. The simplified HW method is 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; Persons – Mulligan, 1978; Kadjo – Garnier – Maye – Martemianov, 2008). 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 equation (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 F_0 is the Fourier number defined by

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

Equation (1) is the analytical solution of an ideal thermal conductive model valid for F_0 >>1 and without convective transfers (Healy – De Groot – Kestin, 1976; Tavman, 1996). From this ideal model and with known q values, the thermal conductivity can be calculated by equation (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. In fact, the $e(t)$ answer to the wire heating $\Delta T(t)$ resultant of the Joule effect due to an electrical current.

$$R(t) = R_0\left(1 + \beta_0\left(T(t) - T_0\right)\right) \tag{4}$$

where $R(t)$ – is the instantaneous electrical resistance of the wire, R_0 – is the resistance of the wire at the T_0 reference temperature, and β_0 is the temperature coefficient of the wire at 22 °C. Taking into account (3) and (4), the thermal conductivity λ can be calculated as follows:

$$\lambda = \frac{q\,R_0\,\beta_0\,i}{4\pi}\left(\frac{d\,e(t)}{d(\ln t)}\right)^{-1} \tag{5}$$

where $de(t)/d(\ln t)$ is a numerical constant deduced from the experimental data and from the linear part of the $e(t) = f(\ln(t))$ curve (Wakeham - Nagashima, 1991, Carslaw – Jaeger, 1959).

RESULTS AND DISCUSSION

Measurements were performed on two bioethanol samples – marked as Bioethanol No 1 and Bioethanol No 2. Samples were made in Slovakia by two different producers. Bioethanol samples were stored at laboratory temperature 24 hours before the measurement.

Table 1

Statistical evaluation of the measured values for λ thermal conductivity for bioethanol samples

Statistical evaluation of the measured values λ for thermal conductivity at 20 °C		
	Bioethanol	
	sample No 1	**sample No 2**
The arithmetic average; $W.m^{-1}.K^{-1}$	0.102	0.114
Standard deviation; $W.m^{-1}.K^{-1}$	± 0.024	± 0.033
Probable error; $W.m^{-1}.K^{-1}$	± 0,001	± 0.002
Relative probable error; %	± 0.98	± 1.75
Statistical evaluation of thermal conductivity graphical dependencies for temperature range (20 - 29) ° C		
Type of function	Polynomial function	
The arithmetic average of values λ; $W.m^{-1}.K^{-1}$	0.114	0.102
Minimum value; $W.m^{-1}.K^{-1}$	0.080	0.180
Maximum value; $W.m^{-1}.K^{-1}$	0.196	0.067
Polynomial Coefficients		
degree 0	1.59	1.52
degree 1	- 0.110	- 0.104
degree 2	0.00201	0.0019
Coefficient of Determination (R-squared)		
degree 0	0	0
degree 1	0.927	0.937
degree 2	0.980	0.994

The results of the first series are presented in tables 1 – 2. The sample marked as bioethanol No1 had smaller thermal conductivity but higher thermal diffusivity. In general, both bioethanol samples had similar values of thermal conductivity - Bioethanol No1 to 0.102 $W.m^{-1}.K^{-1}$ and Bioethanol No 2 - 0.114 $W.m^{-1}.K^{-1}$. For both samples at 20 °C were obtained thermal diffusivity values: Bieoethanol No1 - $1.010.10^{-7}$ $m^2.s^{-1}$; Bioethanol No2 $0.912.10^{-7}$ $m^2.s^{-1}$. For all parameters were calculated following statistical data: arithmetic average, standard deviation from the arithmetic average, the probable error and the relative probable error in percentage. The largest relative probable error in % had measurement of thermal conductivity for sample No2 which was ± 1.75 %. The smallest probable error in % had measurement of thermal diffusivity for sample No1 - 0.57 %.

The obtained results can be compared only to the thermal conductivity values of bioethanol, where literature references indicate range (0.100 to 0.120) $W.m^{-1}.K^{-1}$. Values of thermal diffusivity of bioethanol samples are considered as one of the benefits of this research.

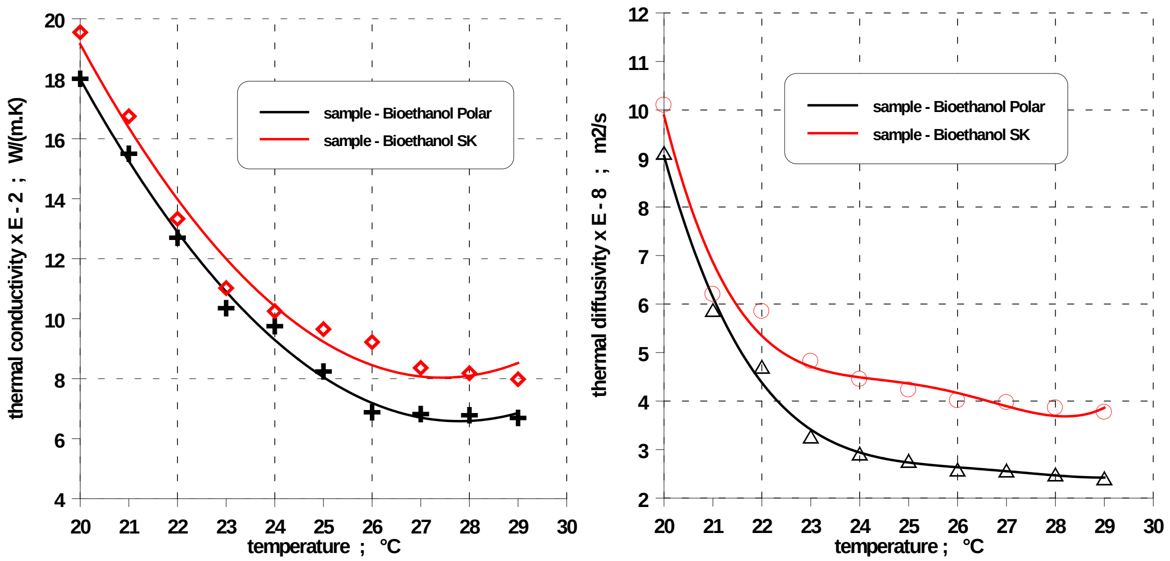
Table 1

Statistical evaluation of the measured values a for thermal diffusivity for bioethanol samples

Statistical evaluation of the measured values a for thermal diffusivity at 20 °C			
		Bioethanol	
		sample No 1	**sample No 2**
The arithmetic average; x 10^{-7} $m^2.s^{-1}$		1.010	0.912
Standard deviation; x 10^{-7} $m^2.s^{-1}$		± 0.028	± 0.031
Probable error; x 10^{-7} $m^2.s^{-1}$		± 0.0012	± 0.0017
Relative probable error; %		± 0.57	± 0.84
Statistical evaluation of thermal diffusivity graphical dependencies for temperature range (20 - 29) ° C			
Type of function		Polynomial function	
The arithmetic average of values *a*; x 10^{-7} $m^2.s^{-1}$		1.404	1.313
Minimum value; x 10^{-7} $m^2.s^{-1}$		1.28	1.21
Maximum value; x 10^{-7} $m^2.s^{-1}$		1.59	1.52
Polynomial Coefficients			
degree 0	x 10^{-7}	271.168	148.066
degree 1		- 42.67	- 22.052
degree 2		2.514	1.234
degree 3		- 0.0657	- 0.03069
degree 4		0.00064	0.00029
Coefficient of Determination (R-squared)			
degree 0		0	0
degree 1		0.955	0.955
degree 2		0.958	0.968
degree 3		0.965	0.992
degree 4		0.975	0.995

In the second series of measurement were examined dependencies of thermal conductivity and thermal diffusivity on temperature. Graphical relations are presented on Figures 1 and 2.

Measurements were performed in temperature interval from laboratory temperature till 29 °C. Each point of graphical dependence is the arithmetic average obtained of the ten repetitive experiments for each temperature. The temperature dependences of thermal conductivity can be described by decreasing polynomial functions of second degree and relations of thermal diffusivity can be described by decreasing polynomial functions of fourth degree. The presented results showed that all graphical dependencies have relatively high coefficients of determination which were from 0.937 to 0.995.



Figures 1, 2 Relations of thermal conductivity and thermal diffusivity to temperature for samples – Bioethanol Polar – No 1 and Bioethanol SK- No 2.

CONCLUSION

Thermophysical properties of bioethanol samples were measured and analyzed in this paper. Effect of temperature or storage temperature on used bioethanol samples was searched. Thermophysical parameters of materials depend mostly from its composition. Thermal conductivity and thermal diffusivity of the samples was measured by digital thermal analyzer Isomet 2104 which principle is based on simplified hot wire method. Temperature dependencies of bioethanol samples had decreasing polynomial shape for all measurements (Figure 1, 2). Coefficients of determination are very high in all measurements (Table 1 and 2). On the base of presented results from thermophysical parameters measurements is clear that it is necessary to have knowledge about thermophysical parameters during temperature changes, because temperature is one of the most important factors which determine quality of the materials.

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