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Experimental investigations on the liquid thermal conductivity of five saturated fatty acid methyl esters components of biodiesel

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ABSTRACT

The utilization of biodiesel is a promising way to replace fossil fuels, and thermal conductivity of biodiesel is a very important thermophysical property for its applications. In this work, the transient hot-wire instrument with one bare platinum wire was used to measure the thermal conductivity of five pure components of biodiesel in liquid phase at atmospheric pressure. The measured substances include methyl butyrate, methyl pentanoate, methyl caproate, methyl caprylate, and methyl pelargonate, and the temperature range was from (283 to 358) K, (285 to 362) K, (263 to 368) K, (273 to 393) K, (278 to 383) K, respectively. The total standard uncertainty of the experimental results was estimated to be less than 2% and the repeatability was better than ±0.5%. The thermal conductivity data of each substance were fitted as a function of temperature. The average absolute relative deviation and maximum absolute relative deviation between the experimental data and calculated results were 0.17% and 0.44% for methyl butyrate, 0.25% and 0.58% for methyl pentanoate, 0.16% and 0.44% for methyl caproate, 0.15% and 0.47% for methyl caprylate, 0.15% and 0.33% for methyl pelargonate, respectively.

1. Introduction

The fossil fuels such as natural gas, petroleum products, coal etc. are playing a crucial role in human progress and social improvement. However, at present, unabated combustion of the remaining reserves of fossil fuels will cause severe climate change (e.g., global warming and air pollution) [1–3]. Under such circumstances, other alternative energy resources are required to fulfill the energy consumption. Therefore, it has been the new focus of plenty of researchers in worldwide to develop dimethyl-ether, ethanol and biodiesel as renewable and alternative fuels [4–9].

Among these fuels, biodiesel, which comprises the saturated an unsaturated fatty acids esters from vegetables oils (corn, soy, and cotton seed oil), animal fats or the hybrid of all of them, is a sustainable fuel because it can be directly used in conventional diesel engine without significant modifications. The transesterification of triglycerides with one short-chain alcohol can produce it, such as the ethanol and methanol, which is able to lead to the formation of fatty acid ethyl esters (FAEEs) and fatty acid methyl esters (FAMEs), respectively. Biodiesels have many apparent benefits, such as being biodegradable, non-toxic, and derived from renewable energy resources. Moreover, relevant tests show that they also have total miscibility with petrodiesel and compatibility with modern engines [10–13]. Thus, biodiesel is able to be directly applied into existing diesel engines without modifications. However, the thermophysical properties of both bio- and petroleum-based diesels, such as thermal conductivity, density, surface tension and compressibility, are different due to the differences in chemical structure [14–17].

The thermal conductivity of biodiesel is a very important thermophysical property and is necessary for the thermal design in an extensive range of areas [18–22]. However, there is no report associated with the experimental data about their thermal conductivities. In this paper, the thermal conductivity of five components of biodiesel, including methyl butyrate, methyl pentanoate, methyl caproate, methyl caprylate and methyl pelargonate, was measured in liquid phase at atmospheric pressure.

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2. Experimental

2.1. Principle of experiment

The transient-hot-wire method is considered to be one of the most accurate and reliable methods to measure thermal conductivity in the liquid phase [23–25]. A single hot wire or two different length hot wires are usually optional. The method of two wires is more precise and can cancel the end effects, but the method of single wire has advantages in calculating the occurrence time of natural convection and heat transfer of thermal radiation, and the measuring circuit is much simpler. In this paper, the thermal conductivity for methyl butyrate, methyl pentanoate, methyl caproate, methyl caprylate and methyl pelargonate in the liquid phase was measured using a transient hot-wire instrument with one bare platinum wire. The basic working equation is as follows [23]:

$$\Delta T_{id}(r_0, t) = \frac{q}{4\pi\lambda}\ln t + \frac{q}{4\pi\lambda}\ln\left(\frac{4a}{r_0^2 C}\right) \quad (1)$$

where ΔT_{id} refers to the ideal temperature rise of wire, r_0 stands for the radius of hot wire, t represents the elapsed time, q refers to the power input per unit length of wire, λ stands for the thermal conductivity of fluid, a symbolizes the thermal diffusivity of fluid, and $C = 1.781\ldots$ stands for the exponential of Euler's constant. Equation (1) demonstrates that there exists a linear relationship between the ideal temperature rise and the logarithm of the elapsed time t. The thermal conductivity λ is obtained by the following equation:

$$\lambda(T, P) = \frac{q}{4\pi k} \quad (2)$$

where $\lambda(T, P)$ refers to the thermal conductivity of fluid at reference temperature T and the working pressure P, k stands for the slope of the line that fits the temperature rise in the ideal condition as a function of the logarithm of the elapsed time t, as shown in Eq. (3):

$$k = \frac{d(\Delta T_{id})}{d(\ln t)} \quad (3)$$

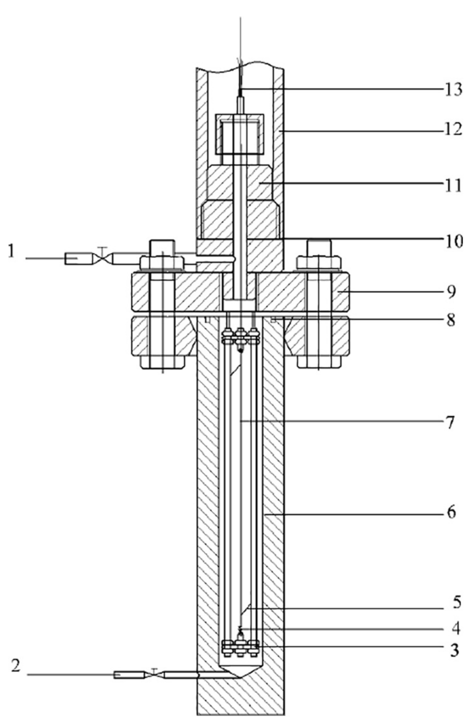

Fig. 1. Thermal conductivity experimental cell.

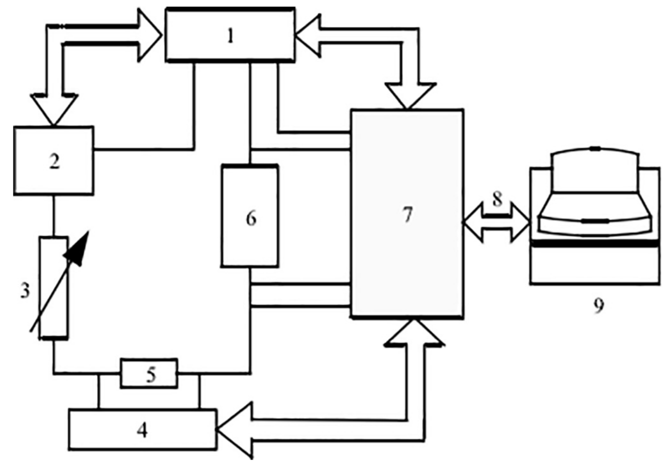

Fig. 2. System of data acquisition. 1:Keythley 7001 2:Keythley 2400 3:resistance box 4:Keythley 2010 5:standard resistance 6:experimental apparatus 7:Keythley 2010 8:IEEE 488 9:computer.

Detailed corrections for the thermal conductivity measurements using transient hot-wire instrument have been illustrated in many literatures [23,26–28] and were not shown here.

2.2. Experimental measurements

The experimental system for thermal conductivity measurement consists of a transient hot wire cell, data acquisition system,

Table 1
Chemical specifications.

Chemical name	CAS number	Source	Initial mass fraction purity	Purification method	Final mass fraction purity
Water	7732-18-5	Aladdin	0.999	None	0.999
Ethanol	64-17-5	Aladdin	0.998	None	0.998
Methyl butyrate	623-42-7	Aladdin	0.99	None	0.99
Methyl pentanoate	624-24-8	Aladdin	0.99	None	0.99
Methyl caproate	106-70-7	Aladdin	0.99	None	0.99
Methyl caprylate	111-11-5	Aladdin	0.97	None	0.97
Methyl pelargonate	1731-84-6	Aladdin	0.97	None	0.97

Table 2
Liquid thermal conductivity of water and ethanol at pressure p = 0.1 MPa[a] (λ_{exp}: experimental data, λ_{ref}: reference data, Dev.% = 100(λ_{exp}-λ_{ref})/λ_{exp}).

T/(K)	λ_{exp}/(W·m^{-1}·K^{-1})	λ_{ref}/(W·m^{-1}·K^{-1})	Dev.%
Water			
293.09	0.6056	0.5980	1.27
299.55	0.6130	0.6089	0.68
309.83	0.6313	0.6241	1.15
314.96	0.6399	0.6309	1.43
319.56	0.6399	0.6366	0.52
324.64	0.6492	0.6424	1.06
332.53	0.6555	0.6505	0.77
339.33	0.6570	0.6567	0.05
340.41	0.6654	0.6576	1.19
349.41	0.6723	0.6645	1.17
Ethanol			
276.51	0.1719	0.1724	−0.27
280.80	0.1687	0.1713	−1.50
284.27	0.1699	0.1704	−0.28
290.37	0.1677	0.1688	−0.67
293.43	0.1658	0.1681	−1.34

[a] Standard uncertainties u are $u(T)$ = 10 mK, $u(p)$ = 1 kPa, combined relative standard uncertainties u_{rc} are $u_{rc}(\lambda exp)$ = 0.02 and $u_{rc}(\lambda_{ref,\ water})$ = 0.007[29], and the relative expanded uncertainty U_r is $U_r(\lambda_{ref,\ ethanol})$ = 0.025 (0.95 level of confidence) [30].