American J. of Engineering and Applied Sciences 1 (3): 200-203, 2008
ISSN 1941-7020

Thermal Effusivity Measurement of Virgin Coconut Oil-Methanol Mixtures using Photoacoustic Technique

Firas Kamel Mohamad Al-asfoor, W. Mahmood Mat Yunus, Azmi Zakaria, Mohd Maarof Moksin, Noor Jawad Ridha and L.Y.C. Josephine
Department of Physics, Faculty of Science, Universiti Putra Malaysia,
43400 UPM Serdang, Malaysia

Abstract: Thermal effusivity of virgin coconut oil-methanol mixtures were measured using open photoacoustic cell technique. The samples were prepared by simply mixing virgin coconut oil and methanol using similar procedure applied for preparation of biodisel. Thermal effusivity of the sample was obtained by fitting the experimental data of photoacoustic amplitude signal to the expression of photoacoustic signal as a function of chopping frequency. Thermal effusivity of mixtures decrease between 0.0851 W $s^{1/2}$ K^{-1} cm^{-2} (pure virgin coconut oil) and 0.0644 W $s^{1/2}$ K^{-1} cm^{-2} (pure methanol) with the increasing of methanol in the mixture.

Key words: Photoacoustic cell, virgin coconut oil, methanol, biodisel, methanol mixture

INTRODUCTION

The ability of a material to exchange its thermal energy with surroundings is essentially determined by its thermal effusivity. Its importance lies not only on the thermal exchange characteristics, but also on its utility in making complete thermophysical property of materials. The thermal effusivity is one of the important and unique thermophysical parameter of material. A simple relationship between thermal effusivity and thermal conductivity of material is given as:

$$e_s = (k\rho c)^{1/2} \quad (1)$$

where ρ, k and c are the density, thermal conductivity and the specific heat of material. Therefore, one can expect that any change in one of these parameters should result in change of the thermal effusivity value[1].

The utility of the photoacoustic (PA) technique for measuring thermal diffusivity or thermal effusivity of materials has been well reported in the literatures[1,2,7-14]. Among them the open photoacoustic cell detection is easy and simple to construct for measuring the thermal effusivity of liquid sample. The basic principle of this technique consists of measuring the acoustic wave as a result of the absorption of intensity-modulated radiation in a photoacoustic cell[2].

The liquid state plays an important role in science and technology. Therefore measuring thermal properties of liquid are needed in many branches of physics and engineering. For instant, thermal diffusivity and thermal effusivity of oils are important to be measured because of their widespread use as refrigerants, lubricants and heat exchanger[3,4]. Virgin coconut oil might be one of the candidates for those applications.

Virgin Coconut Oil (VCO) is one of the best cooking oil and resistant to mutations of fatty acid chains even when used at higher temperature. It is rich in lauric acid, cupic acid and rich with nutrient that supports the body immune system. The common methods to produce virgin coconut oil is wet-milling methods where it does not involve the direct heating or chemical reaction[5]. On the other hand virgin coconut oil is rich in polysaturated fat and a good candidate for biodiesel[6]. This paper reports the thermal effusivity of virgin coconut oil-methanol mixtures measured at room temperature 25°C using photoacoustic technique.

MATERIALS AND METHODS

The experimental set up used for measurement of the thermal effusivity consisted of a He-Ne laser (05-LHR-828), home made photoacoustic cell, mechanical chopper (SR540) and lock-in amplifier (SR530). Modulated optical radiation at 632.8nm with a power level of 30 mW was used for the measurements. The experimental set up is shown in Fig. 1. Both the virgin coconut oil and methanol are optically non-absorbers at

Corresponding Author: W. Mahmood Mat Yunus, Department of Physics, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Malaysia Tel: + (603)89466684 Fax: + (603)89454454

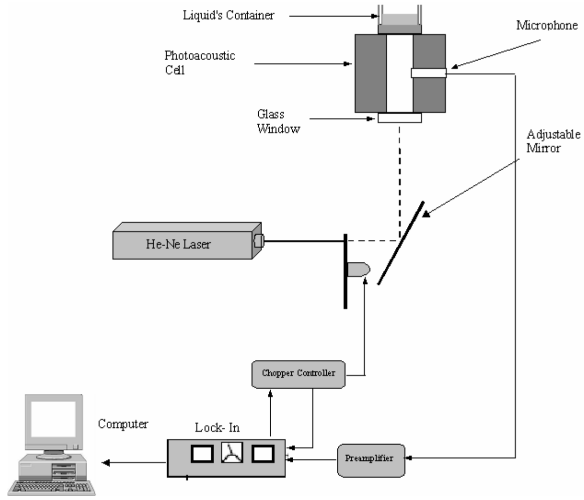

Fig. 1: Experimental setup of open photoacoutic technique

this wavelength (632.8 nm). Investigations were carried out at room temperature. The liquid sample holder was made of a rubber tube of 10 mm high and 8 mm diameter. The bottom of the tube was closed by a 0.067 mm thick aluminium foil. The aluminum foil was illuminated at the surface in contact with air in photoacoustic cell. For measurement of thermal effusivity of liquid half of the sample holder was filled with liquid sample. The photoacoustic signals was detected using an electret microphone and was processed using a lock-in amplifier[7-14]. The amplitude and phase signals were recorded as a function of laser beam modulation frequency for both, empty cell and after filling the cell with the liquid sample. In the present work, only the photoacoustic amplitude signal was analyzed to obtain the thermal effusivity values of the sample.

The liquid samples used in this study were virgin coconut oil and a mixture of coconut oil and methanol. The sample mixtures were prepared by mixing the heated coconut oil with methanol to produce a sample mixture of 10, 20, 30, 40, 50, 60, 70, 80 and 90% V/V. The mixture was made at PH 9 by adding a small amount of catalyst and kept for 24 hours before any measurement was done.

RESULTS AND DISCUSSION

The amplitude of PA signal was inversely proportional to the chopping frequency. The signal produced by empty sample holder (Al foil) was greater than Al-liquid sample. This indicates that the liquid act as heat sink or apart of the thermal energy generated by the sample was absorbed by the liquid due to the finite thermal conductivity of the liquid.

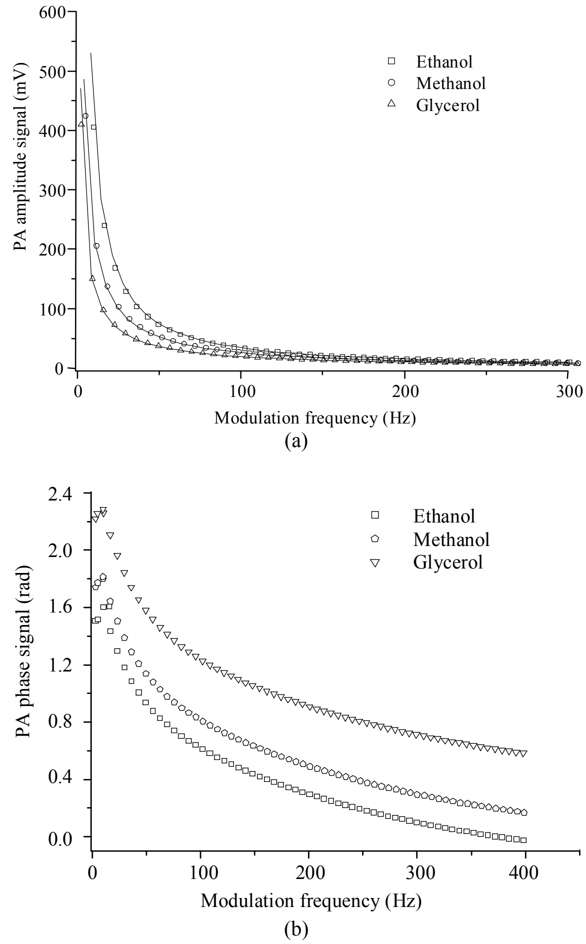

Fig. 2: The Photoacoustic signals as a function of the modulation frequency for the ethanol, methanol and glycerol. (a) Photoacoustic amplitude signal. (b) Photoacoustic phase signal

The pressure fluctuation in an open photoacoustic cell can be written as[8].

$$|\delta P| = \frac{P_1}{f^{p2}\left(1+\frac{P_3}{\sqrt{f}}+\frac{P_3^2}{2f}\right)^{1/2}} \tag{2}$$

where P_3 is defined as $P_3 = \frac{2\varepsilon_s}{\varepsilon_{Al} L_{Al}}\left(\frac{\alpha_{Al}}{\pi}\right)^{1/2}$ and, P_1 and P_2 are constants.

By fitting the experimental data to Eq. 2 we obtained P_3 thus the thermal effusivity can be easily calculated. Figure 2 shows the amplitude and phase

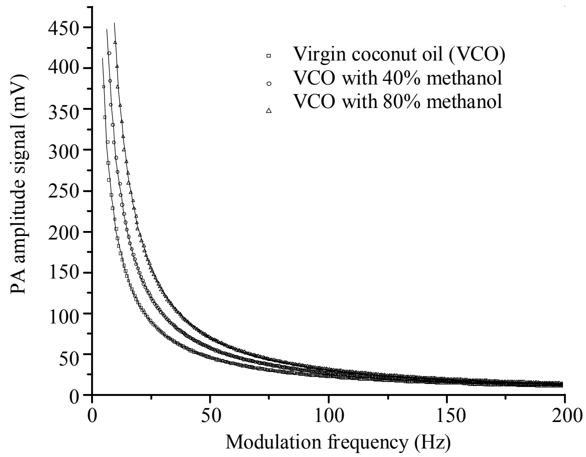

Fig. 3: The photoacoustic signal as a function of the modulation frequency for virgin coconut oil and coconut oil-mixture

Table 1: Thermal effusivities of ethanol, methanol and glycerol obtained using the photoacoustic amplitude signal analysis and known literature values

Liquid sample	Measured effusivity ($W\ s^{1/2}\ K^{-1}\ cm^{-2}$)	Reported values ($W\ s^{1/2}\ K^{-1}\ cm^{-2}$)	Reference
Ethanol	0.0524	0.0567	3 2a 2b
		0.0523	
		0.0558	
Methanol	0.0644	0.0629	3
Glycerol	0.0902	0.0934	9 2a 2b
		0.092	
		0.0939	

a) The value obtained by amplitude analysis, b) The value obtained by phase analysis

signals of ethanol, methanol and glycerol measured at room temperature which has been used to verify the present experimental set up of the open photoacoutic cell technique. The values of thermal effusivity for these three standard samples obtained using the present set-up are listed in Table 1. Our values are in good agreement with the reported values published earlier[2,3].

In order to obtain the thermal effusivity of the sample, the standard samples were replaced with virgin coconut oil sample and coconut-methanol mixture samples. Figure 3 shows a typical of photoacoustic amplitude signal for pure virgin coconut oil and coconut oil samples mixed with 40 and 80% of methanol. The smooth curves show the fitting line obtained by calculating the thermal photoacoustic amplitude as a function of chopping frequency as suggested by Eq. 2. The thermal effusivity and density of coconut oil and coconut oil-methanol samples as a function of methanol concentration are shown in Fig. 4. The thermal effusivity values decrease with the increasing of methanol component in the mixture.

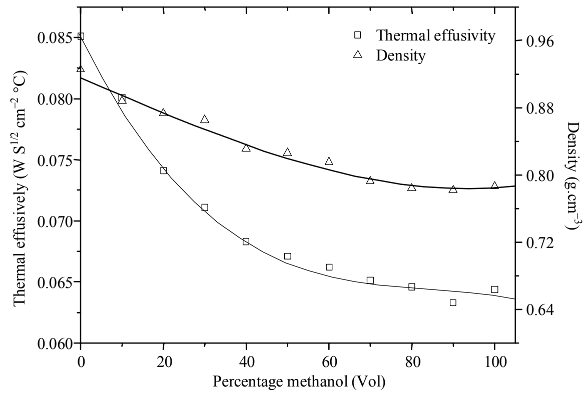

Fig. 4: Thermal effusivity and density measured at room temperature as a function of methanol in the solution

Table 2: Thermal effusivity values of virgin coconut -methanol mixture obtained using the photoacoustic amplitude signal analysis

Methanol in virgin coconut oil mixtures	Measured effusivity ($W\ s^{1/2}\ K^{-1}\ cm^{-2}$)	Reported values ($W\ s^{1/2}\ K^{-1}\ cm^{-2}$)	Reference
Pure VCO	0.0851	N/A	
10%	0.0801	N/A	
20%	0.0741	N/A	
30%	0.0711	N/A	
40%	0.0683	N/A	
50%	0.0671	N/A	
60%	0.0662	N/A	
70%	0.0651	N/A	
80%	0.0646	N/A	
90%	0.0633	N/A	
Pure methanol	0.0643	0.0629	3

This behavior can be simply described by polynomial empirical expression.

$$\varepsilon = a + b(x) + c(x)^2 + d(x)^3 \qquad (3)$$

where a, b, c and d are constants and, x represents the composition of methanol in the solution. Table 2 summarizes the effusivity values obtained for virgin coconut oil and virgin coconut oil-methanol mixtures. The sample density was also shown a similar behaviour as it decreases with increasing of the methanol component in the solution.

CONCLUSION

Thermal effusivity of virgin coconut oil and coconut oil-methanol mixture were successfully measured using open photoacoustic cell technique. The thermal effusivity of the sample was obtained by fitting the experimental data of photoacoustic amplitude signal to the expression of photoacoustic signal as a function of chopping frequency. Thermal effusivity of virgin coconut oil obtained in this study is 0.0851 W $s^{1/2}$ K^{-1} cm^{-2} and this value decreases with the increasing the methanol component in the mixture.

ACKNOWLEDGEMENT

We gratefully acknowledge the Department of Physics, UPM for providing the research facilities to enable us to carry out this research. One of the authors (W.M. Mat Yunus) would like to acknowledge the MOSTI and Academy of Science, Malaysia for the financial support through Fundamental research grant and SAGA programs.

REFERENCES

1. Sikorska, A., B.B.J. Linde and W. Zwirbla, 2005. Study of thermal effusivity variations in water solutions of polyethylene glycol 200 using photoacoustic method. Chem. Phys. Lett., 320: 31-36. doi: 10.1016/j.chemphys.2005.06.024. http://dx.doi.org/10.1016/j.chemphys.2005.06.024.
2. Balderas-López, J.A., 2007. Thermal effusivity measurements for liquids: A self- consistent photoacoustic methodology. Rev. Sci. Instrum., 78: 064901. doi: 10.1063/1.2744333 http://dx.doi.org/10.1063/1.2744333.
3. Jayadas, N.H., K.P. Nair and G. Ajithkumar, 2007. Tribological evaluation of coconut oil as an environment-friendly lubricant. Tribol. Int., 40: 350-354 doi: 10.1016/j.triboint.2005.09.021.
4. Jayadas, N.H., K.P. Nair, 2006. Coconut oil as base oil for industrial lubricants-evaluation and modification of thermal, oxidative and low temperature properties Tribol. Int., 39: 873-878. doi:10.1016/j.triboint.2005.06.006
5. Mat Yunus, W.M., Y.W. Fen and L.M. Yee, 2009. Refractive Index and Fourier Transform Infrared Spectra of Virgin Coconut Oil and Virgin Olive Oil. Am. J. Appl. Sci., 6 2: 328-331. http://www.scipub.org/fulltext/ajas/ajas62328-331.pdf
6. Tan, R.R., A.B. Culaba and M.R.I. Purvisc, 2004. Carbon balance implications of coconut biodiesel utilization in the Philippine automotive transport sector. Biomass Bioenergy 26: 579-585. doi: 10.1016/j.biombioe.2003.10.002
7. Balderas-López, J.A., G. Juarez, M.R. Fonseca and F. Sinencio, 1999. Measurements of thermal effusivity of liquids using a conventional photoacoustic cell. Rev. Sci. Instrum., 70: 2069-2071. doi: 10.1063/1.1149713 http://dx.doi.org/10.1063/1.1149713
8. Castro, M.P.P., A.A. Andrade, R.W.A. Franco, P.C.M.L. Miranda, M. Sthel, H. Vargas, R. Constantion and M.L. Baesso, 2005. Thermal properties measurements in biodiesel oils using photothermal techniques. Chem. Phys. Lett., 411: 18-22. doi: 10.1016/j.cplett.2005.06.003 http://dx.doi.org/10.1016/j.cplett.2005.06.003
9. Balderas-López, J.A., D. Acosta-Avalos, J.J. Alvarado, O. Zelaya-Angel, F. Sanchez-Sinerrio, C. Falcony, A. Cruz-Orea and H. Vargas, 1995. Photoacoustic measurements of transparent liquid samples: Thermal effusivity) Meas. Sci. Technol., 6: 1163-1168. doi: 10.1088/0957-0233/6/8/011 http://dx.doi.org/10.1088/0957-0233/6/8/011
10. Delgado-Vasallo, O. and E. Marin, 1999. The application of the photoacoustic technique to the measurement of the thermal effusivity of liquid. J. Phys. D: Appl. Phys. 32: 593-597. doi: 10.1088/0022-3727/32/5/014 http://dx.doi.org/10.1088/0022-3727/32/5/014
11. Delgado-Vasallo, O., A.C. Valdes, E. Marin, J.A.P. Lima, M.G. Da Silva, M. Sthel, H. Vargas, S.L. Cardoso, 2000. Optical and thermal properties of liquids measured by means of an open photoacoustic cell. Meas. Sci. Technol.,11: 412-417. doi: 10.1088/0957-0233/11/4/311 http://dx.doi.org/10.1088/0957-0233/11/4/311>
12. George, S.D., A.K. George, P. Radhakrishnan,V.P.N. Nampoori and C.P.G. Vallabhan, 2007. Photoacoustic studies on thermal parameters of liquid crystal mixtures. Smart Mater. Struct., 16: 1298-1301. doi: 10.1088/0964-1726/16/4/042.
13. George, N.A., C.P.G. Vallabhan, V.P.N. Nampoori, A.K. George and P. Radhakrishnan, 2001. Photoacoustic evaluation of the thermal effusivity in the isotropic phase of certain comb-shaped polymers. J. Phys. Condens. Matter., 13: 365- 371. doi: 10.1088/0953-8984/13/3/301 http://dx.doi.org/10.1088/0953-8984/13/3/301
14. George, N.A., C.P.G. Vallabhan, V.N. Nampoori and A.K. George, 2001. Use of an open photoacoustic cell for the thermal characterisation of liquid crystals. Appl. Phys., 73: 145-149. doi: 10.1007/s003400100622.