UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND APPLICATION OF FIBER OPTIC- BASED THERMAL WAVE RESONANT CAVITY TECHNIQUE FOR MEASUREMENT OF THERMAL DIFFUSIVITY OF LIQUIDS

Monir Noroozi

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By

Monir Noroozi

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

August 2007

DEDICATION

Specially Dedicated to My Beloved Family
And to My Beloved ONE ...

and

My supervisor Assoc. Prof. Dr. Azmi Zakaria

for his guidance, advice and endless supports

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the requirement for the degree of Master of Science

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Chairman: Associate Professor Azmi Zakaria, phD

Faculty: Science

In the study a thermal wave resonant cavity technique (TWRC) was set up and was used to measure thermal diffusivity of various types of liquids. In this technique the thermal diffusivity was determined by scanning the cavity length, instead of frequency, that has a high signal-to-noise ratio in thermally thick case.

By using metal foil that attached to a tube as the thermal wave (TW) generator the calibration of the conventional TWRC set up was done on distilled water and the thermal diffusivity value, i.e. 1.44×10^{-3} cm^2/s, agrees with literature value. Further, a few liquids thermal diffusivity, including crude palm (0.988×10^{-3} cm^2/s), soy bean (1.06×10^{-3} cm^2/s), corn oil (0.934×10^{-3} cm^2/s), were determine by using this set up. In this set up the TW is enough to be regarded as rays reflecting and transmitting in cavity.

Later the metalized optical fiber tip was used to generate TW instead of metal foil attached to a tube as in the case of conventional TWRC technique. A polymer optical fiber tip or free end coated with silver conductive paint was used to generate TW, by moving this tip with respect to detector and the liquid thermal diffusivity was obtained in a thermally thick region. The thermal diffusivity of distilled water, glycerol, and five different types of cooking oil used which are sunflower, soy bean, olive, corn and palm oils were determined with four-significant-figure at room temperature. These values are in good agreement to the values reported in literatures. The TW field was calculated in a three-dimensional approach. The calculations show that the dimensionality of the TW field in the cavity depends on the lateral (radial) heat transfer boundary conditions and the relation between the laser beam spot size and TW generator diameter. The three-dimensional treatment of the metalised fiber tip was reduced to one-dimensional treatment by using a relatively bigger TW generator diameter compared to laser beam spot size.

The set up using optical fiber end also was used to determine thermal diffusivity of a two-layer which is normally difficult to achieve in the conventional large area metal foil due to contact problem. In order to check the validity of the proposed model, the method was experimentally tested for distilled water and glycerol; the values obtained were close to the literature values. A good linear relation of the amplitude with respect to cavity length in thermally thick region of both media was observed.

In other TWRC methods the thermal diffusivity values can be obtained by measuring the relative distance of two adjacent extrema. The thermal diffusivity values were obtained by this method compare with “fitting data” method.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PEMBANGUNAN DAN PENGGUNAAN TEKNIK RONGGA RESONAN GELOMBANG TERMA BERASASKAN GENTIAN OPTIK BAGI PENGUKURAN RESAPAN TERMA CECAIR

Oleh

MONIR NOROOZI

Agust 2007

Pengerusi: Professor Madya Azmi Zakaria, phD

Fakulti: Sains

Dalam kajian ini susunan peralatan teknik rongga resonan gelombang terma (RRGT) telah digunakan untuk mengukur resapan terma bagi beberapa jenis cecair. Menggunakan teknik ini resapan terma telah ditentukan dengan mengimbas panjang rongga, dan bukannya frekuensi, yang mempunyai nisbah isyarat-ke-hingar yang tinggi dalam kes tebal secara terma.

Dengan menggunakan kerajang logam yang dilekatkan kepada suatu tiub sebagai penjana gelombang terma (GT), penuntukuran dari susunan RRGT yang konvensional telah dilakukan dengan menggunakan air suling dan nilai resapan terma i.e. 1.44×10^{-3} cm^2/s, adalah sesuai dengan nilai literatur. Seterusnya, resapan terma beberapa cecair, termasuk minyak sawit mentah (0.988×10^{-3} cm^2/s), minyak kacang soya (1.06×10^{-3} cm^2/s) dan minyak jagung (0.934×10^{-3} cm^2/s), telah ditentukan menggunakan susunan peralatan ini. Di dalam susunan ini adalah

memadai untuk menganggapkan GT sebagai sinaran yang terpantul dan terpancar di dalam rongga.

Seterusnya hujung gentian optik polimer bersalut logam telah digunakan untuk menjana GT bagi menggantikan kerajang logam yang dihubungkan kepada tiub seperti di dalam kes teknik RRGT konvensional. Hujung “bebas” gentian optik polimer yang disalut dengan cat perak telah digunakan untuk menjana GT, dengan menggerakkan hujung ini terhadap pengesan dan resapan terma cecair telah diperoleh di dalam kawasan yang tebal secara terma. Resapan terma bagi air suling, gliserol, dan lima jenis minyak masak yang berbeza digunakan iaitu minyak bunga matahari, minyak kacang soya, minyak zaitun, minyak jagung dan minyak sawit mentah, telah ditentukan dengan empat angka bererti pada suhu bilik. Nilai-nilai yang diperoleh adalah bersesuaian dengan nilai-nilai yang telah dilaporkan dalam literatur. Medan GT telah dikira dalam pendekatan tiga-dimensi. Hasil pengukuran menunjukkan bahawa dimensi medan GT di dalam rongga bergantung kepada keadaan-keadaan sempadan pemindahan haba pada sisi (jejari) dan hubungan di antara saiz bintik pancaran laser dan diameter penjana GT. Pendekatan tiga-dimensi bagi hujung gentian bersalut logam telah dikurangkan kepada pendekatan satu-dimensi dengan menggunakan penjana GT dengan diameter lebih besar berbanding dengan saiz bintik pancaran laser.

Susunan peralatan menggunakan hujung gentian optik telah digunakan untuk menentukan resapan terma dwi-lapisan yang pada kebiasaannya sukar diperoleh menggunakan kerajang logam luas konvensional disebabkan oleh masalah sentuhan. Model ini mengambilkira pantulan GT dan transmisi pada dua antaramuka; iaitu udara-cecair dan cecair-transduser, dalam penghasilan isyarat fotopiroelektrik. Bagi menyemak kesahihan model yang dikemukakan, kaedah ini diuji secara eksperimen ke atas air suling dan gliserol; nilai yang diperoleh adalah hampir dengan nilai literatur. Hubungan linear yang baik di antara amplitud dan panjang rongga dalam kawasan yang tebal secara terma bagi kedua-dua medium telah diperhatikan.

Dalam kaedah-kaedah RRGT lain, nilai-nilai resapan terma boleh juga diperolehi dengan mengukur jarak relatif dua ekstrema bersebelahan. Nilai-nilai resapan terma telah diperolehi dari kaedah ini dibandingkan dengan kaedah "fitting".

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First and foremost, I would like to extend my praise to Allah s.w.t. that gives me the patience, strength, determination, and courage to produce this thesis.

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Finally, I wish a great pleasure to acknowledge from my family who have helped and supported throughout my study.

Monir Noroozi

I certify that an Examination Committee met on 30nd August 2007 to conduct the final examination of Monir Noroozi on her Master of Science thesis entitled “Development and Application of Fiber Optic- Based Thermal Wave Resonant Cavity Technique for Measurement of Thermal Diffusivity of Liquids" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree.

Members of the Examination Committee are as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as partial fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were follows:

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Date: 15 November 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MONIR NOROOZI

Date: 20 October 2007

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LIST OF ABBREVIATIONS

1-D	One-Dimensional
3-D	Three-Dimensional
Bi	Biot number
BPPE	Back-Detection PPE
Cu	Copper
CW	Continuous Wave
DPSS	Diode Pumped Solid State
FPPE	Front-Detection PPE
He-Ne	Helium- Neon Laser
IPPE	Inverse PhotoPyroelectric
LED	Light-Emitting Diode
LIA	Lock-in Amplifier
LIPS	Laser Induced Plasma Spectroscopy
NDE	Non-Destructive Evaluation
PA	Photoacoustic
PAS	Photoacoustic Spectroscopy
PDS	Photothermal Deflection Spectroscopy
PVDF	Polyvinlidene Difluoride
PPE	PhotoPyroelectric
PPES	Photopyroelectric spectroscopy
PE	Pyroelectric
PT	Photothermal
R-G theory	Rosencwaig-Gersho theory

SPPE	Standard PPE
TiO_2	Titanium Oxide
TWRC	Thermal Wave Resonant Cavity
TW	Thermal Wave
TWG	Thermal Wave Generator

LIST OF SYMBOLS

k	Thermal Conductivity
α	Thermal Diffusivity
ρ	Density
$\eta_{NR}(\lambda)$	Nonradiative Coefficient
β	Optical Absorption Coefficient
L_s	Sample Thickness.
c	Specific Heat
e	Thermal Effusively
μ_β	Optical Absorption Length
f	Modulation Frequency
I_0	Power density
μ	Thermal Diffusion Length
ξ	Thermal Transit Time
t	Time
T	Temperature Field
σ	Complex TW Diffusion
R	Reflectivity of the Sample

CHAPTER 1

INTRODUCTION

1.1 Introduction

Thermal diffusivity is one of the most important specifications of material, which also reflect thermal carrier behavior in the liquids. The thermal-wave resonator cavity (TWRC) technique, one of photothermal (PT) techniques, which base on the generation and detection of thermal waves (TW), in a given sample, is a result of heating due to intensity modulated laser source. TWRC technique has a general applicability and adaptability to many areas of research, as a result of its high resolution thermophysical characterization of solid, liquid, and gaseous samples. Theoretical expressions, one-dimensional (1-D) thermal wave field approach, are usually based on general PPE detection theory and have a variety of modifications depending on the cavity configuration applied in the experiments. However, the 1-D simplification become unjustified, especially in cases of cavity lengths very large compared with the thermal diffusion length and small diameter of laser beams and metal foil, the actual distribution of the thermal-wave source and the TWRC length require a 3-D approach (Matvienko and Mandelis, 2006).

In this work, thermal diffusivity of various liquid samples has been investigated by using the conventional TWRC technique, i.e. by using metal foil as TW generator. This