



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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WAVE RESONANT CAVITY TECHNIQUE FOR MEASUREMENT OF
THERMAL DIFFUSIVITY OF LIQUIDS**

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. $1.44 \times 10^{-3} \text{ cm}^2/\text{s}$, agrees with literature value. Further, a few liquids thermal diffusivity, including crude palm ($0.988 \times 10^{-3} \text{ cm}^2/\text{s}$), soy bean ($1.06 \times 10^{-3} \text{ cm}^2/\text{s}$), corn oil ($0.934 \times 10^{-3} \text{ cm}^2/\text{s}$), 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

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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), penentuan dari susunan RRGT yang konvensional telah dilakukan dengan menggunakan air suling dan nilai resapan terma i.e. $1.44 \times 10^{-3} \text{ cm}^2/\text{s}$, adalah sesuai dengan nilai literatur. Seterusnya, resapan terma beberapa cecair, termasuk minyak sawit mentah ($0.988 \times 10^{-3} \text{ cm}^2/\text{s}$), minyak kacang soya ($1.06 \times 10^{-3} \text{ cm}^2/\text{s}$) dan minyak jagung ($0.934 \times 10^{-3} \text{ cm}^2/\text{s}$), telah ditentukan menggunakan susunan peralatan ini. Di dalam susunan ini adalah

memadai untuk menganggap 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 RRGTT 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 diperolehi 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 RRG T 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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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.

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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



TABLE OF CONTENTS

| | Page |
|---|-------------|
| DEDICATION | ii |
| ABSTRACT | iii |
| ABSTRAK | v |
| ACKNOWLEDGMENTS | viii |
| APPROVAL | ix |
| DECLARATION | xi |
| LIST OF TABLES | xv |
| LIST OF FIGURES | xvi |
| LIST OF ABBREVIATIONS / SYMBOLS | xxi |
| | |
| CHAPTER | |
| | |
| 1 INTRODUCTION | |
| 1.1 Introduction | 1 |
| 1.2 Photothermal Process | 2 |
| 1.3 Pyroelectric Detection | 2 |
| 1.4 Thermal Wave Resonator Cavity Technique | 3 |
| 1.5 Photothermal Technique using Optical Fiber Probe | 4 |
| 1.6 Thermal Properties of Materials | 5 |
| 1.7 Research Problem | 6 |
| 1.8 An Introduction to Liquid | 6 |
| 1.9 Objectives | 7 |
| 1.10 Layout of Thesis | 7 |
| | |
| 2 LITERATURE REVIEW | 8 |
| 2.1 Historical developments of Photothermal | 8 |
| 2.2 Indirect Detection | 10 |
| 2.2.1 Photoacoustic Technique | 11 |
| 2.2.2 Photothermal Deflection | 12 |
| 2.3 Direct Detection | 12 |
| 2.3.1 PPE Detection Technique | 13 |
| 2.3.2 PPE Technique Advantage | 17 |
| 2.3.3 Application of PPE in TWRC Technique | 18 |
| 2.4 TWRC Technique | 20 |
| 2.4.1 Application of TWRC Technique in Measurement Thermal Diffusivity | 21 |
| 2.4.2 Development of the TWRC of Cavity Length Scanning | 23 |
| 2.4.3 Effect of TW Generator in TWRC Technique | 23 |
| 2.5 Thermally Inhomogeneous System | 26 |
| 2.6 Green Function in TW | 28 |
| 2.7 Application of Optical Fiber | 29 |
| | xii |



| | | |
|----------|---|-----------|
| 2.8 | Photothermal Techniques Application in Thermal Diffusivity Measurement | 31 |
| 3 | THEORY AND BACKGROUND | 33 |
| 3.1 | Introduction | 33 |
| 3.2 | Focused Irradiation on a Homogeneous Sample | 33 |
| 3.3 | One-Dimensional Theoretical approach | 35 |
| 3.3.1 | Thermal Diffusivity of Liquid Sample | 35 |
| 3.3.2 | Thermal Diffusivity of Two Layers | 39 |
| 3.4 | Green's Functions in Thermal-Wave | 43 |
| 3.4.1 | Fundamental Green Function Solutions and the Infinite Space | 44 |
| 3.5 | Three-Dimensional Model | 46 |
| 3.5.1 | 3- D Model Used to Describe TWRC Technique | 48 |
| 3.5.2 | Green Function Formalism in Cylindrical Coordinates of Thermal waves | 51 |
| 3.6 | Experimental Conditions and Approximations to the Model | 58 |
| 3.7 | Simulation Results for Three-Dimensional Model of a Semi-Infinite Solid | 59 |
| 3.7.1 | The Effect of Biot Number | 61 |
| 3.7.2 | The Effect of Thermal Diffusivity | 62 |
| 4 | METHODOLOGY | 64 |
| 4.1 | Introduction | 64 |
| 4.2 | Experimental Setup | 64 |
| 4.2.1 | The Conventional TWRC Technique, Using Metal Foil | 65 |
| 4.2.2 | The TWRC Technique, Using Optical Fiber Free End | 68 |
| 4.3 | Accessories (Components of Experimental Setup) | 70 |
| 4.3.1 | Sources | 70 |
| 4.3.1a | Diode Pumped Green Laser | 71 |
| 4.3.1b | Helium-Neon Laser | 71 |
| 4.3.2 | Pyroelectric Detector | 71 |
| 4.3.3 | Lock-in Amplifier | 72 |
| 4.3.4 | Optical Chopper | 72 |
| 4.3.5 | Optical Fiber | 73 |
| 4.3.6 | Silver Conductive Paint | 74 |
| 4.4 | Sample Purpose | 74 |
| 4.5 | Signal Processing and Limitation in Used TWRC technique | 74 |
| 4.6 | System Linearity | 75 |
| 4.7 | Data Analysis | 73 |
| 4.7.1 | Measuring Thermal Diffusion Length in TWRC | 75 |
| 4.7.2 | Slope Fitting Experimental Data in TWRC | 75 |



| | | |
|----------|--|------------|
| 4.7.3 | Measuring Thermal Wavelength in TWRC | 76 |
| 5 | RESULTS AND DISCUSSION | 81 |
| 5.1 | Introduction | 81 |
| 5.2 | Conventional Design of TWRC Technique (Using Copper Foil) | 82 |
| 5.2.1 | Damping in Thermal Wave and Measurement Thermal Diffusivity | 82 |
| 5.2.1.1 | Preliminary Measurements for Water and Olive Oil | 84 |
| 5.2.2 | Thermal Diffusivity of Liquid by Fitting Experimental Data | 87 |
| 5.3 | The TWRC Technique Using Optical Fiber Polymer as TW Generator | 92 |
| 5.3.1 | Thermal Diffusivity of Liquid by Fitting Experimental Data | 93 |
| 5.3.1a | Thermal Diffusivity of One Layer Sample | 94 |
| 5.3.1b | Thermal Diffusivity of Two Layers Sample | 98 |
| 5.3.2 | Determination of Thermal Diffusivity by Measuring Thermal Wavelength | 102 |
| 5.3.3 | Thermal Diffusivity Comparison from Fitting Experimental Data and Thermal Wavelength Measurement | 104 |
| 5.4 | Thermal Diffusivity Measurement by Small Diameter Optical Fiber | 106 |
| 5.4.1 | Comparison PE Signal in Different Size of Optical Fiber | 107 |
| 5.4.2 | Optimization and Limitation of using Optical Fiber in TWRC Technique | 109 |
| 5.4.3 | The Effect of Varying the Relative Size of Optical Fiber as TW Generator and Laser Beam | 110 |
| 5.4.4 | Biot Number Effect | 114 |
| 5.4.5 | Thickness Effect | 116 |
| 5.4.6 | Thermal Diffusivity Effect | 117 |
| 6 | CONCLUSION AND FUTURE DIRECTION | 119 |
| | Introduction | 119 |
| | Conclusion | 119 |
| | Suggestions for Future Work | 122 |
| | REFERENCES | 124 |
| | APPENDICES | 130 |
| | BIODATA OF THE AUTHOR | 151 |
| | LIST OF PUBLICATIONS | 152 |



LIST OF TABLES

| Table | | Page |
|-------|--|------|
| 3.1 | Typical Heat Transfer Coefficients for a Variety of Situations | 61 |
| 3.2 | Physical properties of the some materials at room temperature. | 63 |
| 5.1 | Values of thermal diffusion length, thermal diffusivity and comparison with (some) known literature values. | 86 |
| 5.2 | Thermal diffusivities obtained from amplitude and phase of signal, with copper foil as TW generator and comparison with literature values | 91 |
| 5.3 | Thermal diffusivities obtained from amplitude and phase of signal, with fiber optic as TW generator and comparison with literature values. | 97 |
| 5.4 | Thermal diffusivities of two layer sample measured and comparison with literature values | 101 |
| 5.5 | Thermal diffusivities obtained using using wavelength method and comparison with (some) literature values. | 103 |
| 5.6 | Values of thermal diffusivity and compared between two methods for respective samples | 105 |
| A.1 | Roots of Eq.(3.40), $\alpha_n = \lambda_n R$ | 132 |



LIST OF FIGURES

| Figure | | Page |
|--------|---|------|
| 1.1 | Side view of a schematic of the TWRC configuration | 3 |
| 2.1 | PT phenomena caused by illumination of a surface by modulated beam of light with several detection techniques | 9 |
| 2.2 | Photoacoustic effect from a sample | 11 |
| 2.3 | Standard photopyroelectric (SPPE) configuration | 14 |
| 2.4 | Inverse photopyroelectric (IPPE) configuration | 16 |
| 2.5 | Schematic diagram of the TWRC | 24 |
| 2.6 | Geometry of a dual-cavity PPE interferometer | 25 |
| 3.1 | 1-D configuration of TWRC showed; the thermal waves are partially reflected and transmitted upon striking the boundaries (<i>g</i> , <i>s</i> , <i>l</i> , <i>p</i> , and <i>b</i>) stands for gas, solid, liquid sample PVDF film and backing, respectively | 36 |
| 3.2 | The 1-D geometry of 2-layer fluids sample: <i>g</i> , gas; <i>s</i> , TW generator; <i>l</i> , medium 1; 2, medium 2; <i>p</i> , PE transducer; <i>b</i> , backing material. TW's are partially reflected and transmitted at interfaces, showing thermally- thin medium 1, thick medium 2, and thin PE transducer | 40 |
| 3.3 | a) Amplitude and b) phase of infinite-domain Green function Eq. (3.22) with thermal diffusivity α as a parameter (Mandelis, 2001) | 45 |
| 3.4 | Ln Amplitude of infinite-domain Green function Eq. (3.22) with thermal diffusivity α as a parameter, at a) $x_0 = 0$, b) $x_0 = 1$ (Mandelis, 2001) | 46 |
| 3.5 | (a) A typical single-mode optical fiber, showing diameters of the component layers (b) end of fiber optic, fiber core as laser beam illuminated area with core and cladding as heated area or TW generator | 47 |
| 3.6 | scheme of the cavity | 49 |
| 3.7 | Three-dimensional circular thermal-wave cavity wall impinged by a modulated Gaussian laser beam | 49 |



| | | |
|-----|--|----|
| 3.8 | Theoretical result for Distilled water obtained by substituting Eq (3.51) for the case of $Bi=0$ and various radius of the cavity cell with $r = 0, 0.2, 0.8$ (cm) | 61 |
| 3.9 | Effect of the thermal diffusivity on the \ln amplitude were obtained by substituting Eq (3.51) for the case of $Bi=0$, for sliver, copper, air and water | 62 |
| 4.1 | Schematic diagram of TWRC technique with metal foil attached to a tube as the generator and He-Ne laser as the excitation source | 65 |
| 4.2 | The photothermal signal-generation chamber, consists of two parallel walls: (copper foil) generator, and (PVDF) detector | 67 |
| 4.3 | 1 mm diameter core of single index polymer fiber was coated with silver conductive paint, showing diameters of the component layer | 68 |
| 4.4 | Schematic diagram of TWRC technique with fiber optic coated by silver paint as the TW generator | 69 |
| 4.5 | Cross section of PVDF from top view | 71 |
| 4.6 | A diagram which illustrates the propagatin of light through a multi-mode optical fiber | 73 |
| 4.7 | Typical results of the pyroelectric signal amplitude vs relative cavity length for distilled water | 78 |
| 4.8 | Phase discontinuity occurs after the complex thermal-wave signal vector completes one full cycle (2π phase rotation) as a function of cavity length | 79 |
| 5.1 | The plot of (PPE normalized amplitude) versus cavity length of a) distilled water b) air | 83 |
| 5.2 | The plot of (PPE signal) versus cavity length of distilled water and olive oil | 85 |
| 5.3 | PVDF signals recorded vs. time for the mixtures of salt dissolved in water, (1) Distilled water in distilled water, (2) one drop of saturated solution of salt in 13 ml of distilled water, (3) five drops of methanol in 10 ml of distilled water. | 88 |
| 5.4 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for a) distilled water and b) Crude Palm Oil | 89 |



| | | |
|------|---|-----|
| 5.5 | PVDF signals recorded vs. time for distilled water, baseline for distilled water, is a steady-state signal various the times. | 93 |
| 5.6 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for distilled water. | 95 |
| 5.7 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Glycerol | 95 |
| 5.8 | The amplitude of the pyroelectric signal on the cavity length for two layers fluids: Air and Distilled Water | 99 |
| 5.9 | The amplitude of the pyroelectric signal on the cavity length for two layers fluids: Air and Glycerol | 99 |
| 5.10 | TWRC signal phase for distilled water. The jump is deliberately shown as discontinuities between $-\pi$ and $-\pi + \varepsilon$ radians | 102 |
| 5.11 | Typical behavior of the a) PE Ln amplitude and b) phase versus the cavity length for distilled water, by 0.1 mm core diameter fiber optic | 106 |
| 5.12 | Typical behavior of the PE amplitude versus the cavity length for distilled water, by using fiber optic with different core diameter, 1mm (big) and 0.1mm (small) | 107 |
| 5.13 | Typical behavior of the PE phase versus the cavity length for distilled water, by using fiber optic with different core diameter, 1mm (big) and 0.1mm (small) respectively. | 108 |
| 5.14 | Figure 5.14: Temperature field versus radial distance of water at a) different TW generator radius (R), and fixed laser spot size $w=0.03$ cm, b) different laser spot size (w), fixed TW generator radius $R=0.15$ cm, with $\alpha_l = 1.45 \times 10^{-3}$ cm ² /s, $f=6.7$ Hz, $z=2\mu_l$ and $Bi=0$. | 112 |
| 5.15 | In amplitude vs cavity length scans simulation of distilled water, with different Biot number, from 0 to 100, where $f = 6.7\text{Hz}$, $w = 0.1\text{cm}$, $R = 0.3(\text{cm})$ and $\alpha_w = 0.00144(\text{cm}^2/\text{s})$ | 114 |
| 5.16 | Distance radius scan simulation of, a) distilled water, b) silver, at different thickness, 0, 0.004 and 0.1cm respectively, where. $f = 6.7\text{Hz}$, $w = 0.1\text{cm}$, $R=0.3\text{cm}$ and $Bi = 0$ | 116 |
| 5.17 | Distance radius scan simulation of samples with different thermal diffusivities, silver, air and water, respectively, where $f = 6.7\text{Hz}$, $w = 0.1\text{cm}$, $l = 0.1\text{cm}$ and $Bi = 0$ | 118 |



| | | |
|-----|---|-----|
| A.1 | The Bessel functions of the first kind of order zero and of order first, J_0 and J_1 respectively. | 131 |
| A.2 | The Bessel functions of the first kind | 131 |
| A.3 | Roots of Eq.(3.40), $\alpha_n = \lambda_n R$ | 132 |
| A4 | The plotting process, and some toolbar that was used from them in plotting graphs of the theoretical signal by Matcad software | 135 |
| A5 | The front panel diagram of the core VI, the front panel is the user interface | 137 |
| A6 | The block diagram of the core VI, the block diagram contains the source code of the program | 138 |
| A7 | The fitting process of Microcal Origin 7.5 software would be started if the mouse pointer is clicked on Non-linear Curve Fitting command | 140 |
| A8 | Graphic user interface of Microcal Origin 7.5 software in fitting session with the experimental plot and selected data range indicated in background | 142 |
| B.1 | The plot of (PPE signal) versus cavity length of olive oil. It represents the extinction length at which the exponential term is reduced to $1/e$ | 144 |
| B.2 | The plot of (PPE signal) versus cavity length of glycerol. It represents the extinction length at which the exponential term is reduced to $1/e$ | 144 |
| B.3 | The plot of (PPE signal) versus cavity length of sunflower oil. It represents the extinction length at which the exponential term is reduced to $1/e$ | 145 |
| B.4 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Soy bean Oil | 146 |
| B.5 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Corn Oil | 146 |
| B.6 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Sunflower Oil | 147 |
| B.7 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Soy bean Oil | 147 |



| | | |
|------|--|------|
| B.8 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Olive Oil | 14 8 |
| B.9 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Corn Oil | 14 8 |
| B.10 | Typical results of the pyroelectric signal amplitude and phase vs relative cavity length for Palm Oil | 14 9 |
| B.11 | TWRC signal phase for glycerol. The jump is deliberately shown as discontinuities between $-\pi$ and $-\pi + \varepsilon$ radians | 14 9 |
| B.12 | TWRC signal phase for sunflower. The jump is deliberately shown as discontinuities between $-\pi$ and $-\pi + \varepsilon$ radians | 150 |
| B.13 | TWRC signal phase for olive oil. The jump is deliberately shown as discontinuities between $-\pi$ and $-\pi + \varepsilon$ radians | 150 |



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 |
| $\eta_{\text{NR}}(\lambda)$ | 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

