



**UNIVERSITI PUTRA MALAYSIA**

**DEVELOPMENT OF A PHOTOTHERMAL DEFLECTION ANALYZER  
FOR MEASUREMENT OF THERMOPHYSICAL AND THERMO-OPTICAL  
PROPERTIES OF FLUIDS**

**KUAN YA CHIN**

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**MASTER OF SCIENCE  
UNIVERSITI PUTRA MALAYSIA**

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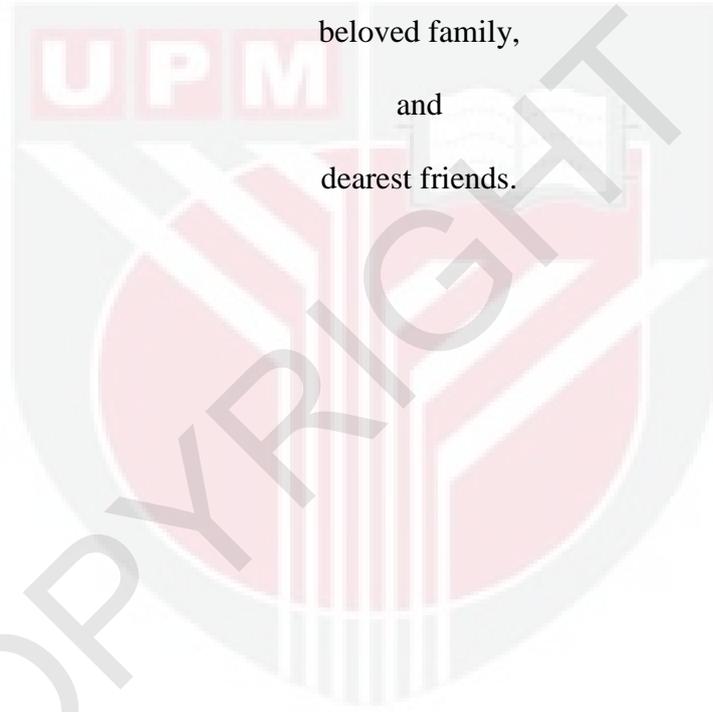
Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in  
Fulfilment of the Requirements for the Degree of Master of Science

March 2008



**To:**

beloved family,  
and  
dearest friends.



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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**KUAN YA CHIN**

March 2008

**Chairman : Associate Professor Ionel Valeriu Grozescu, PhD**

**Faculty : Science**

Photothermal deflection techniques are non-contact methods for optical and thermal properties characterization of solids, liquids and gases. The main focus in this project was to design, construct and test reliability of an instrument based on the principle of photothermal deflection technique. In this technique, the heating source is a NiCr resistance wire and the probe beam is a CW HeNe. The instrument is intended for the characterization of thermal properties of liquids and it is named Photothermal Deflection Analyzer (PTDA).

The PTDA setup consists mainly of a CW HeNe probe laser beam, a NiCr resistance wire, a position sensitive detector and a personal computer with an installed data acquisition card. The PTDA measured the deflection of a probe beam passing near a heating source immersed in a liquid sample. The beam deflection is caused by the refractive index gradient induced by the temperature change in the liquid. The deflection angle of the probe laser beam is measured by the position sensitive

detector. Short electrical pulses from a data acquisition card generated across the resistance wire cause a heating gradient in the liquid. The duration and temporal shape of the electrical pulses can be change in a wide range.

The temperature distribution of the heating wire and liquid is simulated by solving numerically a coupled transient heat conduction equations for wire and liquid. The effect of different temporal profiles and pulse durations of the heating source to the temperature distribution in the liquid is discussed. Using obtained temperature profile it is possible to calculate the probe beam displacement. Thermal properties of the liquid can be determined by comparing the numerical and experimental probe beam displacement.

In order to test the reliability of the PTDA, thermal properties of selected liquid samples: distilled water, alcohol, sodium chloride liquid solution and coconut oil were determined. The thermal properties for distilled water and alcohol show a good agreement with the literature. For sodium chloride liquid solution, the PTDA is sensitive enough to sense the changes of thermal properties due to the variation of the solution concentration. The thermal diffusivity of coconut oil was dependent to the moisture content whereas the thermal conductivity and thermo-optical properties was not affected by the moisture content. Presently to the best of our knowledge, there is no literature data on thermal properties of coconut oil versus moisture content.

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

**PERKEMBANGAN SATU PENGANALISA SESARAN FOTOTERMA  
UNTUK PENENTUAN SIFAT TERMOFIZIKAL DAN TERMOOPTIKAL  
BAGI CECAIR**

Oleh

**KUAN YA CHIN**

March 2008

**Pengerusi : Profesor Madya Ionel Valeriu Grozescu, PhD**

**Faculty : Sains**

Teknik pesongan fototerma merupakan satu teknik tak bersentuh untuk pencirian sifat optik dan haba bagi pepejal, cecair dan gas. Fokus utama dalam projek ini adalah untuk mereka, membina dan menguji kebolehpercayaan satu alat penganalisa berdasarkan teknik pesongan fototerma. Dalam teknik ini, unit pemanasan ialah NiCr dawai rintangan dan sinaran laser ialah CW HeNe. Alat ini bertujuan untuk pencirian sifat haba bagi cecair and dinamakan sebagai Penganalisa sesaran fototerma.

Penyusunan alat-alat untuk teknik pesongan fototerma terdiri daripada satu laser CW HeNe, satu dawai rintangan NiCr, satu pengesan sensitif kedudukan dan satu komputer yang dipasang dengan kad pemerolehan data. Penganalisa sesaran fototerma mengukur pesongan sinaran laser yang melalui penjana haba yang direndam dalam sampel cecair. Pemesongan sinaran laser ini dicetus oleh perubahan indeks pembiasan yang disebabkan oleh perubahan suhu dalam sampel cecair. Sudut pesongan sinaran laser ini diukur dengan menggunakan pengesan sensitif kedudukan.

Denyut elektrik yang daripada kad pemerolehan data yang dijana merentasi dawai rintangan menyebabkan perubahan pemanasan dalam sampel cecair. Tempoh dan bentuk denyut elektrik pulse boleh diubah.

Taburan suhu dalam dawai pemanas dan cecair telah disimulasi dengan menyelesaikan dalam bentuk angka gandingan persamaan haba kekonduksian singkat bagi dawai dan cecair. Kesan perbezaan profil masa dan tempoh denyut daripada sumber pemanasan terhadap taburan haba dalam dawai pemanas dan cecair juga dibincangkan. Dengan menggunakan taburan suhu yang diperolehi pesongan sinaran dapat dikirakan. Sifat terma dapat ditentukan dengan membandingkan model berangka dan data eksperimen.

Untuk menguji kebolehpercayaan penganalisa sesaran fototerma, sifat terma bagi cecair ujian terpilih: air suling, alkohol, cecair sodium klorida dan minyak kelapa dapat ditentukan. Nilai sifat terma bagi air suling dan alkohol adalah dekat dengan nilai rujukan. Bagi cecair sodium klorida, penganalisa sesaran fototerma adalah peka untuk mengesan perubahan sifat terma untuk kepekatan cecair yang berubah-ubah. Nilai keteresapan bagi minyak kelapa adalah bergantung kepada kandungan air sebaliknya kekonduksian terma dan sifat termooptikal tak bergantung kepada kandungan air. Masa kini dalam pengetahuan yang ada, tidak ada data rujukan dalam nilai sifat terma untuk minyak kelapa dengan kandungan air.

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

**IONEL VALERIU GROZESCU, PhD**

Associate Professor  
Physics Department  
Faculty of Science  
Universiti Putra Malaysia  
(Chairman)

**W. MAHMOOD MAT YUNUS, PhD**

Professor  
Physics Department  
Faculty of Science  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 12<sup>th</sup> June 2008



## DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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**KUAN YA CHIN**

Date: 11<sup>th</sup> April 2008



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## LIST OF ABBREVIATIONS

AC	Alternating current
ADC	Analog-to-digital converter
CFD	Combined finite difference Method
CW	Continuous Waveform
DAQ	Data acquisition
DC	Direct current
FDM	Finite difference method
FEM	Finite element method
GPIB	General Purpose Interface Bus
H	Heater
HeNe	Helium Neon
IC	Integrated circuit
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
NI	National Instrument
NiCr	Nickel Chromium
PC	Personal computer
PCI	Peripheral Component Interconnect
PDA	Personal digital assistant
PDE	Partial differential equation
PSD	Position sensitive detector
PTDA	Photothermal Deflection Analyzer
PVDF	Polyvinylidene fluoride
PXI	PCI extensions for instrumentation

R	Resistance thermometer
TWRC	Thermal Wave Resonant Cavity
VI	Virtual Instrumentation
VXI	VME extensions for instrumentation



## LIST OF SYMBOLS

$A$	Area
$a$	radius of the wire
$\vec{a}_x$	spatial unit vector perpendicular to the original probe beam
$\alpha$	Thermal diffusivity
$\alpha_w$	Thermal diffusivity of wire
$\alpha_f$	Thermal diffusivity of fluid
$C$	Euler's constant
$C_p$	Volumetric specific heat
$D$	Dimensionless wire-probe distance
$D_{diff}$	Diffusion distance
$d$	Distance
$\delta$	Sum of beam deflection
$\delta_f$	Beam deflection in the fluid
$\delta_{air}$	Beam deflection in the air
$\nabla$	Del operator
$E$	Surface emissive power
$\varepsilon$	Emissivity
$F_{1-2}$	View factor in black bodies
$g(r, \tau)$	Dimensionless heat generation rate
$\gamma_1$	Dimensionless variable
$\gamma_2$	Dimensionless variable

$h$	Convection heat transfer coefficient
$I$	Current
$I_{in}$	Current input
$J_0$	Bessel function of first kind of order zero
$J_1$	Bessel function of first kind of order one
$J(x)$	Jacobian matrix
$k$	wave number
$k$	Thermal conductivity
$k_w$	Thermal conductivity of wire
$k_f$	Thermal conductivity of fluid
$k_{12}$	Dimensionless thermal conductivity
$l$	Length of wire
$L_f$	probe beam path length in the fluid
$M$	Total number of grid point
$M_w$	Total number of grid point in wire
$\mu_k$	damping parameters
$n_0$	refractive index
$n_{air}$	Air refractive index
$n_f$	Fluid refractive index
$N_z$	Number of grids along the z-axis
$\nabla n$	Refractive index gradient
$p$	Estimated parameter vector