UNIVERSITI PUTRA MALAYSIA

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

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2008

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By

KUAN YA CHIN

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.

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

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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

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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 kepakatan 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:

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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: 11th 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
α	Thermal diffusivity
α_w	Thermal diffusivity of wire
α_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
δ	Sum of beam deflection
δ_f	Beam deflection in the fluid
δ_{air}	Beam deflection in the air
∇	Del operator
E	Surface emissive power
ε	Emissivity
F_{1-2}	View factor in black bodies
$g(r,\tau)$	Dimensionless heat generation rate
γ_1	Dimensionless variable
γ_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
μ_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
∇n	Refractive index gradient
p	Estimated parameter vector