CORRELATION BETWEEN REFLECTANCE AND REFRACTIVE INDEX OF DIFFERENT LIQUIDS USING AN OPTICAL TIME DOMAIN REFLECTOMETER (OTDR

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To my dearest mother, father and her

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In the name of Allah The Most Gracious, The Most Merciful

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ABSTRACT

Recently, the area of measurement and instrumentation and particularly sensor development has undergone fast development. Among the active advancement of sensor based microelectronics development, the optical based sensor has expanded promisingly over these past years due to its key advantages such as compact size, low power consumption, corrosion and electrical spark free which would cause a fire in the explosive environment, electromagnetic interference proof, high sensitivity and large distance between signal detection that is possibility of enabling a long distance measurements. For instance, refractive index sensors have attracted considerable attention in biological and chemical applications. Thus many optical sensors for refractive index (RI) detection have been proposed. Therefore, this research was carried out in order to seek the correlation between reflectance and refractive index of different liquids using an optical time domain reflectometer (OTDR) via single mode fibre (SMF) of 100m length. There are three objectives that are to observe the fluctuation in the fiber end of the five liquids (water, acetic acid, 1-butanol, 1-octyne and ethyl glycol with their corresponding RI are 1.33, 1.337, 1.40, 1.42 and 1.43), to clarify experimentally the correlation between reflectance with RI of the liquids and to analyze the potential of using the OTDR technique for measurement RI of liquids. Each liquid is measured 10 times in order to obtain good average value of reflectance reading under three different pulse widths (20ns, 50ns and 100ns). After completing the data analysis, the fluctuations in reflection readings of the liquids is within 6%. The experimental and simulation curves are similar in trend and the OTDR technique has the potential in measuring RIs of liquids.

ABSTRAK

Dewasa ini, bidang pengukuran dan instrumentasi terutamanya pembangunan pengesan telah mengalami perkembangan yang pesat. Di kalangan kemajuan pesat pembangunan pengesan berteraskan mikroelektronik, pengesan berteraskan optik telah berkembang dengan jayanya sejak tahun-tahun kebelakangan ini kerana beberapa kelebihan utamanya seperti saiznya yang padat, penggunaan tenaga yang rendah, bebas daripada hakisan dan percikan elektrik yang mana ia boleh menyebabkan kebakaran dalam persekitaran yang mudah meletup, bebas daripada gangguan elektromagnet, daya sensitif yang tinggi dan jarak yang luas akan pengesanan isyarat yang mana ia memungkinkan pengukuran jarak jauh. Sebagai contoh, pengesan indek biasan telah menarik perhatian yang agak merangsangkan dalam bidang biologi dan kimia. Hasilnya, banyak pengesan indek biasan telah dicadangkan. Oleh yang demikian, kajian ini telah dijalankan bagi mencari korelasi di antara pantulan dan indek biasan daripada cecair yang berbeza dengan menggunakan *optical time domain reflectometer* (OTDR) melalui gentian tunggal optik yang panjangnya 100m. Terdapat tiga objektif iaitu untuk memerhatikan flaktuasi dihujung gentian daripada 5 cecair itu (air, asid acetik, 1-butanol, 1-octyne dan ethyl glycol yang mana indek biasan masing-masing ialah 1.33, 1.37, 1.40, 1.42 dan 1.43), untuk memastikan secara eksperimen akan korelasi di antara pantulan dengan indek biasan cecair-cecair itu dan untuk menganalisis akan potensi menggunakan teknik OTDR dalam mengukur indek biasan cecair. Setiap cecair diukur sebanyak 10 kali bagi mendapatkan purata bacaan yang baik dengan tiga lebar denyut yang berbeza (20ns, 50ns dan 100ns). Setelah selesai menganalisis data, flaktuasi dalam bacaan pantulan semua cecair itu di dalam julat 6%. Lengkungan eksperimen dan simulasi mempunyai corak yang sama dan teknik OTDR ini berpotensi untuk mengukur indek biasan cecair.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE

LIST OF ABBREVIATIONS

BSL   Backscattered Light

IOR   Index of Refraction

RI   Refractive Index

SMF   Single Mode Fibre

SPR   Surface Plasmon Resonance

LIST OF SYMBOLS

α	Attenuation coefficient
c	Coupling efficiency
c_{vacuum}	Speed of light in vacuum
c_{medium}	Speed of light in a medium
δ	Reflection height
σ	Backscatter factor
f	Fraction of the scattered light captured at the output end
L	Fibre length
n_1	Refractive index of medium 1
n_2	Refractive index of medium 2
n_{eff}	Effective index of the SMF
$n_{material}$	Refractive index of the material (liquids)
$P_{backscattering}$	Backscattered and reflected optical power
P_{OTDR}	OTDR's received power
R	Reflectance
s	Coefficient of light scattering
τ	Pulse width
ν	Pulse group velocity
x	Position relative to the input end of the fiber

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

One of the important optical parameters of materials is refractive index (RI). From the measurement of RI, other parameters such as density, concentration, temperature and stress can be sensed and detected (Owen, 1967). Thus, according to Stanley (1989) and Meeten (1986) varieties of RI measurement methods have been described. Some of them are fibre surface plasmon resonance (SPR) sensors (Monzón-Hernández and Joel., 2006), photonics crystal waveguide sensors (Skivesen et al., 2008) and microfibers-based sensors (Liao et al., 2011).

Yen et.al (2012) had proposed and demonstrated a RI measurement method using an optical time domain reflectometer (OTDR) fibre based sensor via a single mode fibre (SMF). In the proposed scheme, the RI of different organic chemicals can be detected by measuring the backscattered light (BSL) from the OTDR. It is such a simple method to measure the RI of organic liquids.

1.2 Problem Statement

Research has been done to show the simulation of reflectance with RI (Yen et al., 2012). Hence, the purpose of this research is to clarify experimentally such relationship for five liquid chemicals (water, acetic acid, 1-butanol, 1-octyne and ethyl glycol) by using a 100m SMF and the optical pulse laser from an OTDR is 1310 nm which is set up at three different pulse widths that are 20ns, 50ns and 100ns.

1.3 Research Objective

There are three main objectives in this research which are:-

1) To observe the fluctuation in the fibre end reflection reading of different liquids.

2) To clarify experimentally the correlation between reflectance with RI of the liquid chemicals.

3) To analyze the potential of using the OTDR technique for measurement of RI of liquids.

1.4 Scope of Study

In this research, the wavelength of the ptical pulse laser of the OTDR is 1310nm and it will be set at three different optical pulse widths which are 20ns, 50ns and 100ns. Five different liquid chemicals with known refractive indices will be measured using the OTDR's via a 100m SMF which an effective RI (n_{eff}) of 1.4682. The liquid chemicals are water, acetic acid, 1-butanol, 1-octyne and ethyl glycol. The corresponding RIs of the liquid chemicals are 1.33, 1.37, 1.40, 1.42 and 1.43. For each liquid chemical, it will be measured 10 times in order to obtain a good average value of the reading. Then all the OTDR's traces are analyzed by using Anritsu TraceView 4.1.

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