PHOTO-ACOUSTIC INDUCED BY Q-SWITCHED Nd:YAG LASER DETECTED BY PVDF SENSOR IN DIFFERENT LIQUIDS

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Dedicated to my beloved parents

Mat Rifin b. Seman and Siti Zaharah bt. Mohamad

and my family

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ABSTRACT

A Q-switched Nd:YAG laser beam with short pulsed duration of 6 ns and energy 60 mJ at a wavelength 1064 nm was focused via a camera lens into a glass container occupied by liquid samples. The laser pulse focused at a small area creates an optical breakdown followed by plasma formation. This induced shock wave formation followed by acoustic wave in the liquid medium. The acoustic wave generated was detected using a Piezo sensor coupled with preamplifier of 1 GΩ input impedance. Difference distances of source to transducer were configured. Difference sample solutions such as distilled water, sodium chloride (NaCl) solutions and white grape juice were used. Properties of acoustic wave, such as the attenuation (amplitude voltage), transient pressure, and dominant component frequency were observed. It was found experimentally that spatial extent of the generation breakdown can affect the acoustic signature and Fourier spectrum of photo-acoustic response where the amplitude and the transient pressure of the signals increase when the distance of the source-sensor decrease. The voltage amplitude for white grape juice and distilled water samples at a distance of 10 mm, were 4.57 V and 4.75 V respectively while for the transient pressure, the value were 481.46 kPa and 500.42 kPa respectively. The presence of ions in aqueous solution can also affect its photo-acoustic response due to water molecule association, where OH band strongly attached to hydrogen-bond water molecule and the other part of band deals with free molecules. The attenuation effect in electrolyte solutions (NaCl) was found to be larger, compared to other samples where the amplitude at lower concentration was 0.40V, with pressure of 42.14 kPa. The frequency of photo-acoustic Fourier spectrum for distilled water and white grape juice samples were found at lower frequency ranging from 24 kHz - 60 kHz but for NaCl solutions the frequencies were higher ranging from 44.06 kHz – 144.16 kHz.

ABSTRAK

Sebuah alur laser Nd: YAG suis Q dengan tempoh denyut yang pendek 6 ns dan tenaga 60 mJ dengan panjang gelombangnya 1064 nm difokuskan ke dalam bekas kaca yang diisi dengan cecair sampel melalui kanta kamera. Laser denyut Nd:YAG ditumpukan pada satu kawasan kecil akan mewujudkan runtuhan optik diikuti oleh pembentukan plasma. Ini menyebabkan terhasilnya gelombang kejutan yang kemudiannya diikuti oleh gelombang akustik dalam medium tersebut. Gelombang akustik yang dijana kemudian dikesan menggunakan pengesan piezo yang digandingkan pada pra-pembesar dengan kemasukan impedan 1 GΩ. Perbezaan jarak di antara sumber dan pengesan dilaraskan. Larutan sampel yang berbeza digunakan seperti air suling, jus anggur putih dan larutan natrium klorida (NaCl). Sifat-sifat gelombang akustik, seperti pengecilan (amplitud voltan), tekanan transien dominasi komponen dan frekuensi diperhatikan. Ujikaji ini mendapati bahawa tahap pembesaran sumber penjanaan plasma boleh menjejaskan bentuk akustik dan kesan ke atas sambutan spektrum Fourier fotoakustik di mana amplitud dan tekanan gelombang meningkat apabila jarak dari sumber kepada pengesan dikurangkan. Nilai voltan amplitud dalam kedua-dua sampel (air suling dan jus anggur putih) pada jarak 10 mm, masing-masing ialah 4.57 V dan 4.75 V manakala untuk tekanan masing-masing ialah 481.46 kPa dan 500.42 kPa. Kehadiran ion dalam larutan akueus juga boleh menjejaskan kepada sambutan fotoakustik disebabkan penyatuan molekul air dimana ikatan OH terikat dengan kuat pada molekul air dan ikatan molekul pada bahagian lain mudah terikat pada molekul bebas. Kesan pengecilan tenaga molekul dalam larutan elektrolit (NaCl) didapati menjadi lebih besar, berbanding dengan sampel lain di mana amplitud pada kepekatan yang terendah adalah 0.40V, dan tekanan adalah 42.14 kPa. Spektrum Fourier fotoakustik di dalam air suling dan sampel jus anggur putih didapati pada frekuensi yang rendah iaitu pada julat dari 24 kHz - 60 kHz tetapi dalam larutan NaCl, frekuensinya adalah pada 44.06 kHz – 144.16 kHz.

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A	-	film area
C	-	capacitance
c	-	propagation speed
D	-	charge density developed
d_h	-	piezo hydrostatic constant
d_{31}, d_{33}	-	piezo strain constant
E	-	elasticity modulus,
E_0	-	electric field amplitude
f	-	frequency
f_r	-	frequency of resonance
g_{31}, g_{33}	-	piezo stress constant
I, I_0	-	irradiance
k_{31}, k_t	-	electromechanical coupling factor
Δl	-	change in film length (m)
l	-	original film length (m)
n	-	axis of applied stress or strain
P	-	power (watts)
p	-	pyroelectric constant
Q	-	charge
r	-	distance from centre of the beam
Δt	-	change of thickness
t	-	time, film thickness
V_0	-	output voltage
υ	-	velocity of sound/acoustic wave
Δw	-	change in film width (m)
w	-	original film width (m), radius

X_n, P	-	stress / pressure applied in the relevant direction
x	-	spatial dimension
Z_e	-	electrical impedance
α,	-	absorption coefficient (cm^{-1})
β	-	logarithmic coefficient of thermal expansion of fluid (K^{-1})
C_p	-	specific heat per unit mass of fluid ($J\ g^{-1}\ {}^{o}K^{-1}$).
ε	-	permittivity
ρ	-	density
χ	-	compressibility

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Diagnoses using non-destructive testing (NDT) techniques are used to be the best choice in industrial or medical field to evaluate the properties of material, component or system without causing damage. One of the benefits of NDT is it permanently not alter the surface of the materials during inspection, and this method has become a highly-valuable technique because it can save cost and time in produce evaluation, troubleshooting and research. The common NDT methods include ultrasonic, magnetic particle, liquid penetrated, radiographic and eddy-current testing.

In industrial field, ultrasonic testing commonly used to find flaws in materials and measure thickness of objects. While in medical field, ultrasonic or ultrasound mostly used in sonography to produce pictures of fetus in the women womb. Although the ultrasonic spectroscopy is well known technique in medicine and material analysis, but it has limited resolution of measurements and complicated cleaning and sample handling procedure that prevented this technique in research and analytical laboratories. Also it has been identified that no ultrasonic techniques except inelegant or indirect one technique are available for determining pressures.

Acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration, sound, ultrasound and infrasound. Frequency above and below the audible range are conventionally identify as “ultrasonic” and “infrasonic” respectively, while “acoustic” refer to the entire frequency range without limit.

The research of acoustic wave had been widely explored for many years and still being study until now. An acoustic wave can be utilised as a non-contact method to characterising and monitoring process of liquids in chemical or pharmaceutical industries. Other than that the acoustic wave also had been demonstrated for other applications, such as in physics, engineering, biology and medicine.

In this research, the main study is to focus on laser beam interaction with liquids which feature the procedure using acoustic wave. A Q-switched Nd:YAG laser source was focused through a camera lens into a glass container occupied by liquids samples. The acoustic generated then measured using a piezoelectric Polyvinylidene Fluoride (PVDF) film sensor that placed perpendicular to the axis of the laser source to detect the pressure generated by the acoustic wave. Change of mean square voltage and pressure wave of acoustic emission due to difference distance of source to transducer were observed. Difference liquids samples were used to investigate the influence on the signal. The results obtained, are studied using Fast Fourier Transform. The characterization of the acoustic sensor about the optical absorption measurements for the different sample of liquids is also highlighted in this study.

1.2 Statement of Problem

The photo-acoustic response after the laser pulse excitation can be described by only macroscopic parameters of absorbing media such as absorption coefficient, thermal expansion, heat capacity and etc. However, a typical pulsed photo-acoustic response has rather complicated wave shape and complicated Fourier Spectrum. This technique then had limitedly used in material analyses due to the problems in its design, electronics, sample handling, complicated measuring procedure and resolutions. Thus, in this study, attempts had been made to describe this wave shape or spectrum using the only macroscopic properties of substance and experimental geometry where all possible factors such as sound reflection on the container walls, sound attenuation in liquids, sound velocity dispersion in liquid, material properties and transducer electric properties are taken into account.

1.3 Objective of the Study

In this study, a photo-acoustic wave generate in liquids is developed by interaction of laser beam with the samples. The objectives of the study are:

1. To detect the acoustic wave at different distance.
2. To calibrate and characterize the acoustic pressure using piezoelectric Polyvinylidene Fluoride (PVDF) film sensor.
3. To detect the transient acoustic pressure in the different liquids.
4. To analyze the acoustic wave signal by using Fast Fourier Transform.

1.4 Scope of Study

In this study, the scope is on acoustic wave that was generated by using a Q-switched Nd:YAG laser. The experimental setup consists of the laser system, three different liquid samples, sensor and oscilloscope. The acoustic wave signal was detected by using a piezoelectric Polyvinylidene Fluoride (PVDF) sensor with film thickness 28 µm. The acoustic waveform was analyzed using Fast Fourier transform method and acoustic pressure was calculated using the sensor equation. The acoustic signals were studied in different liquids such as distilled water, sodium chloride (NaCl), and white grape juice. The signals had also been studied at various distances with range of 10 mm to 130 mm.

1.5 Significant of Study

Acoustic wave and ultrasonic spectroscopy are one of the methods applied in material inspection, biological study, medical (tracing tumour in patient body), and in measuring the pollutants. Both of these methods have advantages in detecting tiny concentration of particular gas and non-destructive to the sample or material. Research in detecting the acoustic wave, can improve these techniques so they can be more accurate, more reliable and easier to conduct.

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