Quick and Easy Measurements of the Inherent Optical Property of Water by Laser

Dina Izadi[1], Fereshteh hajiesmaeilbaigi[2]

[1]*Ariaian Young Innovative Minds institute (AYIMI), P.O. Box: 17185-614, Tehran, Iran.*

[2]*Solid State Laser Group, laser and Optics research School, Tehran, Iran.*

E-mail: dinaocean@gmail.com, fbaigi2000@yahoo.com

(Received 15 November 2009; accepted 14 January 2010)

Abstract

To compare properties of different waters we measured the reflectance of the second harmonic of Nd: YAG laser light through different water samples in the laboratory. To generate realistic images of natural waters one must consider in some details the interaction of light with the water body. The diagrams have been utilized to represent effective parameters in the water's reflectivity such as: the angle of incidence or the bottom conditions, height of the laser from water surface, wavelength of the laser light, radiant intensities, depth of water and also the impurities of water. The reflectance of the bottom from a mirror at the bottom of an aquarium with different depths of water will depend on the bottom slope relative to the direction of incidence of the laser light and the coating to prevent damaging the mirror against the laser light so it is necessary to change the mirror after several experiments.

Keywords: Laser light-Inherent, Optical Properties- water.

Resumen

El presente trabajo muestra las mediciones hechas en diferentes líquidos para comparar sus propiedades, tomando como referencia la reflectancia de la segunda armónica de un laser Nd. YAG, esto a través de diferentes muestras de líquidos en el laboratorio. Para poder generar imágenes realistas se debe de considerar algunos detalles de interacción de la luz con el cuerpo líquido. Los diagramas fueron utilizados para representar parámetros efectivos de la reflexión del liquido como puede ser el ángulo de incidencia y las condiciones de fondo, la altura del laser respecto a la superficie del liquido, la longitud de onda de la luz laser, la intensidades de radiación la profundidad del líquido y las impurezas que pudieran existir. La reflexión de la profundidad utilizando un espejo a diferentes profundidades depende de la inclinación relativa a la dirección de incidencia del laser y de la protección del espejo para que no se dañe, por lo que es necesario cambiar el espejo después de varios experimentos.

Palabras clave: Luz láser-inherente, Propiedades ópticas del agua.

PACS: 01.30.M; 01.40.ek; 01.40.Fk; 01.40.gb **ISSN 1870-9095**

I. INTRODUCCTION

The inherent optical properties (IOP) determine the ocean surface color, the quality of underwater visibility, and the transfer rates of heat. The values of the IOP's depend on the type and concentration of the water components, primarily of phytoplankton, suspended sediment, and dissolved and particulate organic material. To measure the IOP's of an active light source through water sample there are two general approaches: 1- isolating water sample from the surrounding environment.2- to measure the natural light within the water column. Measuring the IOP's through a water sample needs some corrections rather than the in situ measurement because the volume of the sample is smaller than the real ocean. Underwater beams pass into the water volume, focused and defocused at different points across the surface. As the rays of light pass down through the volume, some of the light is scattered in other directions, some of the rays are absorbed, and a fraction penetrates down to the floor of a water volume and then reflects. The reflected light from the bottom gives some information from the water surface, the water column, and the bottom [1, 2].

Lasers pulses penetrate tens of meters deep into the ocean in the wavelength range of 450-530 nm. One of the most important tasks in laser remote sensing is to measure the index of attenuation but determination of the spectral absorption coefficient for natural waters is a difficult task (water itself absorbs only weakly at near-UV and blue wavelengths, so that very sensitive instruments are required) and more importantly, scattering is never negligible [2, 3, 4].

There are several parameters which is important to quantify attenuation coefficient in different waters by the second harmonic of Nd: YAG laser light.

II. THEORIES

One key parameter in water optics, to determine and quantify the particulate and dissolved matter in water, is reflectance as in Eq. (1),

$$R(\lambda, z) = I_u(\lambda, z) / I_d(\lambda, z), \quad (1)$$

where λ is the wavelength, z is the depth from the air-sea interface, I_u is upwelling irradiance and I_d is downwelling irradiance [5]. According to Beer's law, the irradiance just below the water surface attenuates with depth [3, 6] so $I(0,\lambda)$ and $I(z,\lambda)$, incident and transmitted rays, respectively, from water surface (0) up to depth (z) change as Eq. (2),

$$I(z,\lambda) = I(0,\lambda) e^{-\int_0^z \varepsilon_0(z',\lambda)dz'}, \quad (2)$$

$$\varepsilon_0(z,\lambda) = -\frac{d\ln I(z,\lambda)}{dz} = -\frac{1}{I(z,\lambda)}\frac{dI(z,\lambda)}{dz} \quad (\mathrm{m}^{-1}), \quad (3)$$

where $\varepsilon_0(z,\lambda)$ is the diffuse attenuation coefficient. There are a variety of ways to define ε_0 in terms of operational measurements. This coefficient have unit of inverse length, and represent the exponential rate of attenuation of light with distance through the medium. We define $\varepsilon_0(z,\lambda)$ as the average over the depth from 0 to *z;*

$$\varepsilon_0(z,\lambda) = \frac{1}{z}\int_0^z \varepsilon_0(z',\lambda)dz'. \quad (4)$$

In order to study reflected pulses $I_r(z,\lambda)$, the bottom reflectance and its type is important then;

$$I_r(z,\lambda) = LI(z,\lambda)\exp(-\varepsilon_0(z,\lambda)z), \quad (5)$$

$$I_r(z,\lambda) = LI(0,\lambda)\exp(-2\varepsilon_0(z,\lambda)z), \quad (6)$$

where, L is the bottom return coefficient that depends on its type [7]. The reflected rays on the surface which have not penetrated through water are 0.04%, according to Beer's law, so we can ignore. Light travels from its source in a divergence form so the beam areas on the air-water interface and the bottom are different. Since $P = \frac{I}{W}$ (W is the spot area) [10], then;

$$\frac{I_r(z,\lambda)}{W_r} = \frac{I(0,\lambda)}{W} L\exp(-2\varepsilon_0(z,\lambda)\times\frac{Z}{\cos(r)}), \quad (7)$$

$$I_r(z,\lambda) = \frac{I(0,\lambda)L\pi R^2}{\pi(\frac{nH+Z}{\cos\theta})^2}\exp(-2\varepsilon_0(z,\lambda)\times\frac{Z}{\cos(r)}). \quad (8)$$

H is the height of the laser from water surface. Direction of the refracted ray is given by Snell's law $n_i \sin\theta = n_r \sin r$ where θ and r are angles with the facet normal for incident and transmitted rays, respectively and n_i, n_r are real indices of refraction for the corresponding media. The index of refraction (relative to air), $n(\lambda, S, T, p)$, decreases with increasing wavelength or temperature, and n increases with increasing salinity or pressure [3, 8].

The quantity $\bar{\mu}_d(z,\lambda)$ and $\bar{\mu}_u(z,\lambda)$ are the spectral downwelling and upwelling average cosine respectively as Eqs. (9) and (10),

$$\bar{\mu}_d(z,\lambda) = \frac{I_d(z,\lambda)}{I_{0d}(z,\lambda)}, \quad (9)$$

$$\bar{\mu}_u(z,\lambda) = \frac{I_u(z,\lambda)}{I_{0u}(z,\lambda)}. \quad (10)$$

The average cosines are crude but useful one-parameter measures of the directional structures of the down welling and upwelling light fields. A useful definition of an average cosine for the entire light field can be made by integrating over all directions in Eq. (11).

$$\bar{\mu}(z,\lambda) = \frac{I_d(z,\lambda) - I_u(z,\lambda)}{I_0(z,\lambda)}. \quad (11)$$

This quantity varies from $\bar{\mu} = 0$ for an isotropic radiance distribution to $\bar{\mu} = \cos\theta_0$ for a collimated beam; thus $-1 < \bar{\mu} < +1$. In natural, sunlit waters $\bar{\mu}$, is always positive. (Note: $\bar{\mu}$ is not equal to the sum of $\bar{\mu}_d$ and $\bar{\mu}_u$) [3].

III. MEASUREMENTES

The measurements were made in an aquarium with distilled water, drinking water and a sample from the Oman Sea (Fig. 1). The second harmonic of the Nd: YAG laser ($\lambda = 532nm, R = 10Hz, \tau = 8-10ns, P = 3MW, E = 280mj$) light after reflecting from a mirror passes through a prism and enters an aquarium. The water's reflectivity varies depending on downward intensities, angle of incident and kind of water [9]. The reflected ray from a coated mirror at the bottom moves close enough to the water's surface and is attenuated as fast as possible. Along the path through the water, a fraction of the ray is scattered into a distribution of directions. However, we measured the sum whole outcome of this process by an energy meter.

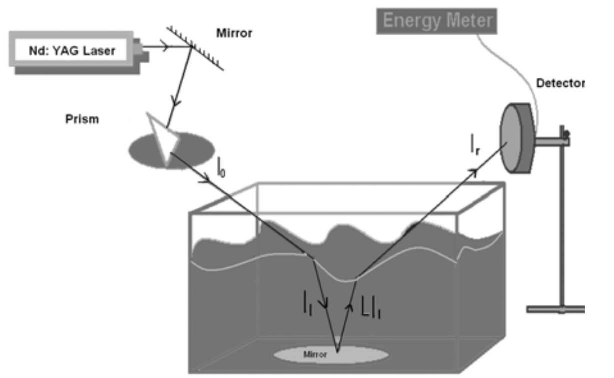
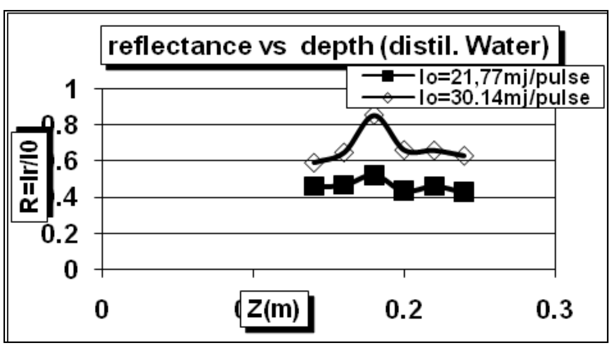
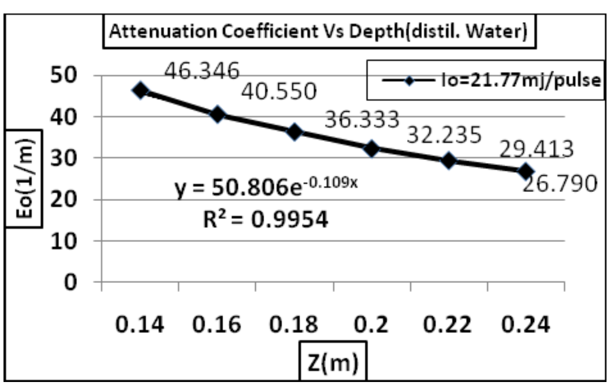
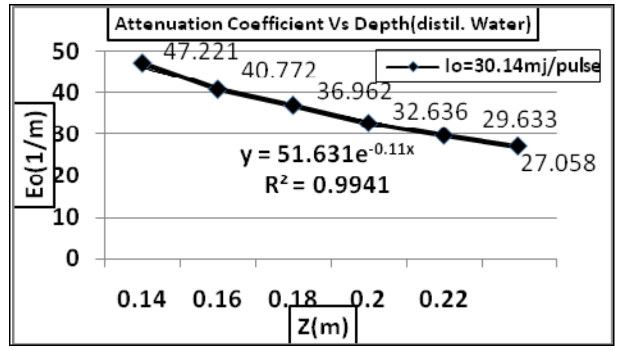


FIGURE 1. Set up of the experiments.

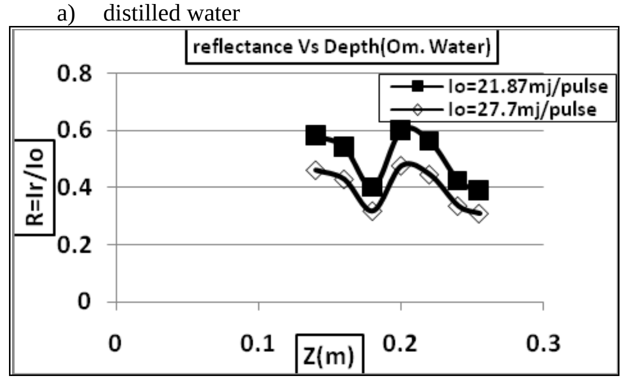
Reflectance parameter, $R = \frac{I_r}{I_0}$ and attenuation coefficient ε_0 will change in different depths of water due to the bottom (mirror) and different water samples. As defined in Eqs. (7) and (8), we measured these parameters with various coated mirrors. After a few measurements the laser light damages these mirrors and this is one of the most important parameters affects R and ε_0. As shown in distilled water the more intensity the more reflectance and ($\varepsilon_\circ$) will be but it is inverse in the saline water from the Oman Sea (Fig. 2). Here in these experiments salinity and dissolved materials caused more radiance absorption.

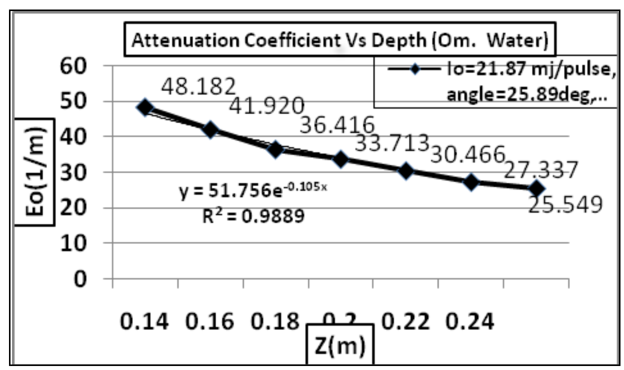


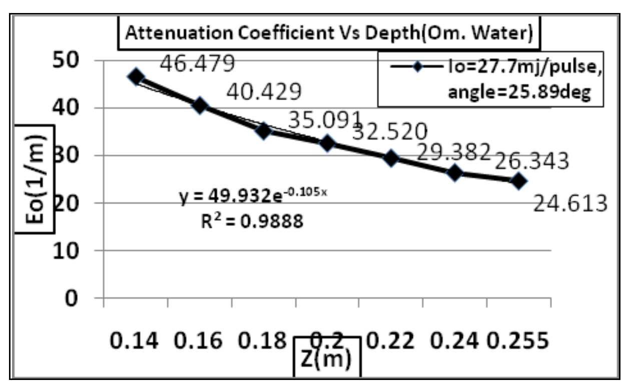




a) distilled water







b) saline water (water sample of Oman Sea)

FIGURE 2. (a) More reflectance and ε_0 due to more intensity and constant angle in different depths, **(b)** Inverse in saline water

All the values of ε_0 show its dependency to the bottom condition and dissolved materials in water samples and it is not the exactly water attenuation coefficient. The values of the inherent optical properties depend on the type and concentration of the water components, like phytoplankton, suspended sediment, dissolved and particulate organic material too. Therefore this approach enables one to obtain the water constituent abundances.

The measurements of the average cosine in two water samples, distilled water and a sample from the Oman Sea (S = 32.3 ppt) show the difference between them (Table 3 - 2). In natural waters $\bar{\mu}\langle 1$ and here $\bar{\mu}_{dist.}\langle\bar{\mu}_{om}$.

TABLE I. the average cosine at different intensities in distilled and saline water ($\bar{\mu}\langle +1$).

α°	$I_{\circ}(mj/pulse)$	$\bar{\mu}(Oman)$	$\bar{\mu}(distiled)$
25.89	21.87	0.31	0.13
25.89	27.7	0.43	0.33
23.56	31.29	0.39	0.23
23.56	18.83	0.38	0.07
23.56	31.62	0.31	
23.56	24.67	0.34	

Different angles of incidence, look like constant angle in various bottom slopes (Fig. 3). For bigger angles (or more bottom slop), where the attenuation coefficient (ε_0) is less, the mirror will be less damaged because the laser light scattering and absorption from the bottom is little.

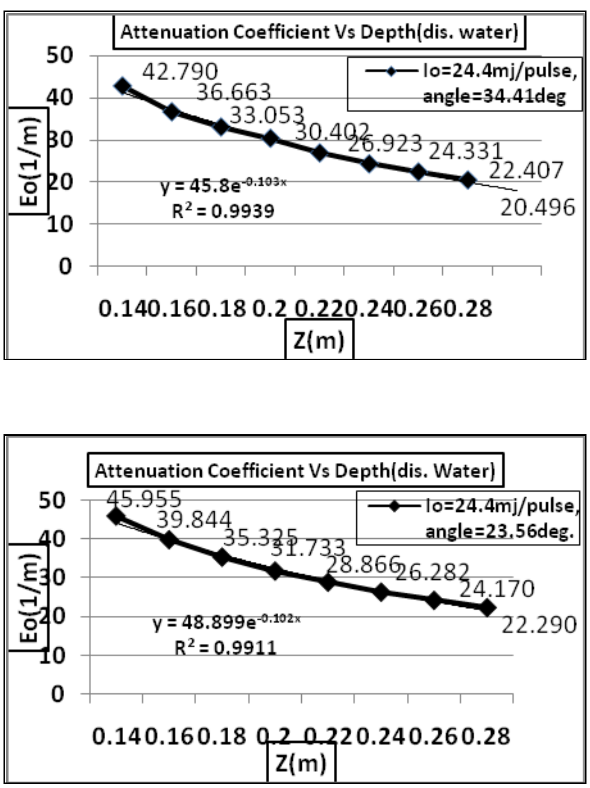


FIGURE 3. Less attenuation coefficients due to bigger angle in different depths (distilled water).

The attenuation coefficients diagrams in different depths but constant angle and intensity is the other way to compare water samples. The more salinity or dissolved materials the more ε_0 will be (Fig. 4).

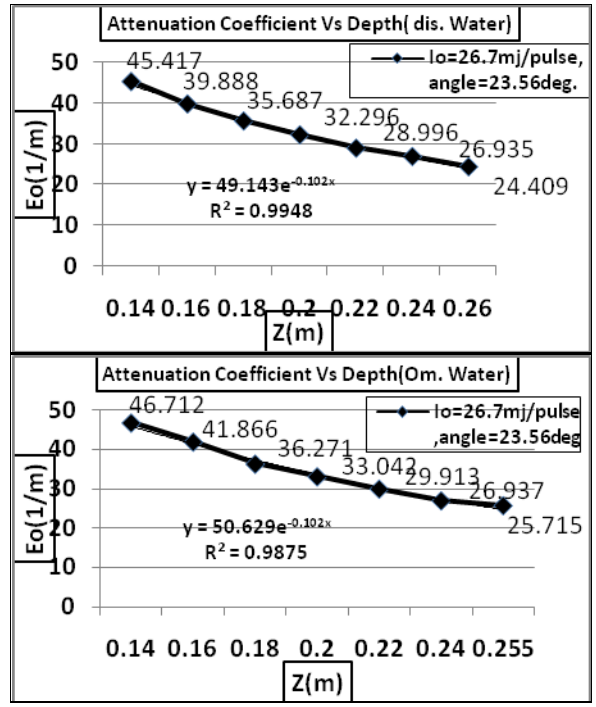


FIGURE 4. More attenuation coefficients due to dissolved materials**,** constant angle and intensity (Oman Sea).

The changes in attenuation coefficient due to the height of water are clearly as in (Fig. 5). By adding more water in the aquarium, the laser light reflectance will be from the layers of water so it will be closer to the large volume of water in the field experiments.

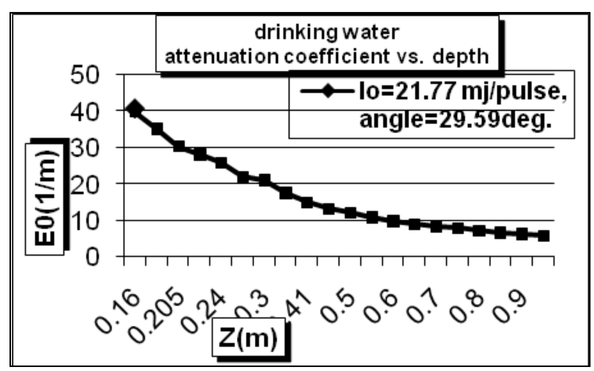


FIGURE 5. Attenuation coefficient decreases as water column increases.

These experiments let us to compare inherent optical properties of different waters with more or less dissolved materials or different pollutants that absorb and scatter light. Now we should think about measuring the thickness of the oil layer or any pollutants on the water surface by this method. Dissolved organic matter, which includes a complex group of compounds varying in molecular size and chemical composition, is one of the components that affect light absorption.

IV. CONCLUSIONS

With the algorithm presented here, we compared the inherent optical properties of different water samples. As it shown, in water with low dissolved particles the higher radiant intensity, the more reflectance will be but in water with more dissolved particles it is inverse. In different depths but constant radiant intensity, the bigger angle of incidence, the smaller ε_0 will be. The reflectance of the bottom depends on the bottom slope relative to the direction of the laser beam and the coating of the mirror. It is necessary to change the mirror after several experiments to prevent it from damaging against the laser light.

Decreasing the attenuation coefficient in different radiant intensity by adding more water to channel, indicates it is necessary to consider the height of the laser above water and the bulk of water above the mirror because the laser light reflectance is from the layers of water.

REFERENCES

[1] Leathers, R. A., Roesler, C. S. and McCormick, N. J., *Ocean inherent optical property determination from in-water light field measurements,* Applied Optics **38**, 5096-5103 (1999).

[2] Mobley, C. D., *Light and Water Radiative Transfer in Natural Waters.* (CD edition). (2004) pp. 60-75.

[3] Bunkin, A. and Voliak, K., *Laser remote sensing of the ocean,* (John Wiley & Sons, Inc, New York, 2001).

[4] Reuter, R. and Diebel, D., *Oceanographic Laser Remote Sensing Measurement of Hydrographic Parameters,* Journal of Remote Sensing **14**, 823-484 (1993).

[5] Froidefond, J. M. and Ouillon, S., *Reflectance measurements above and below the water surface,* Optics Express **13**, 926-936 (2005).

[6] Knauss, A., *Introduction to Physical Oceanography,* (Second Edition, Prentice Hall, Upper Saddle River, New Jersey 07458), (1996) pp. 282-291.

[7] Spitzer, D. and Dirks, R.W.J., *Bottom influence on the reflectance of the sea,* International Journal of Remote Sensing **8**, 279–290 (1987).

[8] Premoˇze, S. and Ashikhmin, M., *Rendering NaturalWaters, COMPUTER GRAPHICS forum,* The Eurographics Association and Blackwell Publishers Ltd Published by Blackwell Publishers **20**, 189–199 (2001).

[9] Pelevin, V. N. and Rostovtseva, V. V., *Modelling of bio-optical parameters of open ocean waters.* Oceanologia **43**, 469–477 (2001).

[10] Philpot, W. D. and Wang, C. K., *Using SHOALS LIDAR System to Detect Bottom Material Change,* IEEE International **5,** 2690- 2692 (2002).