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AN AQUACULTURE WATER CHECKER – DESIGN AND MANUFACTURE

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Abstract. *A real-time, mobile aquaculture water checker is presented. The configuration of double integrating spheres is developed for simultaneously measuring backward scattering R_d, forward scattering T_d and transmitted light T_c. Based on Kubelka-Munk model, a set of optical parameters including absorption coefficient μ_a, scattering coefficient μ_s and anisotropy g are calculated. The obtained results for diluted milk standard samples with different milk concentrations and aquaculture water samples with different densities of Psexdo-Nitzschia-delicatissium algae are also reported.*

I. INTRODUCTION

Harmful algae are always undesirable biomasses in the aquaculture. In ordinary conditions, these algae suspend innocently in the bottom water layer. When the water is polluted (in eutrophic or eutrophication status), they will possibly be blooming and exhausting toxic substances into the medium, making the situation more and more critical, even exterminating aquacultured products in series. Therefore, the harmful algae density is commonly considered as a significant indicator for water pollution gradation.

There exist already traditional harmful algae monitoring methods: Utermohl method [1], Sedgewick Rafter counter [2], cell dye [3], ELISA method [4]. Widely used in Vietnam, they are processed in laboratories, consisting of sampling, calibration diluting, counting the algae through a microscope. There are also methods estimating water pollution by measuring algae fluorescence. But these methods could not be used for non- fluorescent algae. Algae blooming in large water areas could be detected by remote sensing from satellites in connection with field measuring data. This method is effective for macroscopic survey, but costly and complicated [5, 6]. In brief, the above-mentioned methods are all time-consuming and unsuitable to urgent indicator demands and/or in-situ water pollution estimations.

In this paper, a real-time, mobile aquaculture water checker is designed based on Kubelka-Munk model and double integrating spheres technique for determining optical parameters including absorption coefficient μ_a, scattering coefficient μ_s and anisotropy

g- the parameters characterize for aquaculture water samples, in order to estimate in-situ pollution gradation.

II. THEORETICAL BASICS AND EXPERIMENTAL SETUP

Biological samples and aquaculture water in particular, specified by a set of optical parametersμ_a, μ_s and$g$, are described by the following radiative transfer equation [7]:

$$\frac{dI}{ds}(r,s) = -(\mu_a + \mu_s) I(r,s) + \frac{\mu_a + \mu_s}{4\pi} \int_{4\pi} p(s,s') I(r,s') d\Omega' \tag{1}$$

where $I(r,s)$ is the incoming light intensity per solid angle unit at r via s direction, $d\Omega'$- solid angle element and $p(s,s')$- scattering phase function from s' to s.

The most widely used scattering phase function is Henyey-Greenstein function depending on anisotropy g and angle θ between s and s' in the form:

$$p(\cos\theta) = \frac{1}{4\pi} \frac{1-g^2}{(1+g^2-2g\cos\theta)^{3/2}} \tag{2}$$

The parametersμ_a, μ_s, g can be determined by some methods: Monte Carlo simulations, approximation models,....Among the approximation models, Kubelka-Munk model [8] is the usually used one. In accordance with Kubelka-Munk model, the absorption and scattering in the sample can be expressed by following equations:

$$\begin{cases} \dfrac{di_r(x)}{dx} = (K+S) i_r(x) - S i_t(x) \\ \dfrac{di_t(x)}{dx} = S i_r(x) - (K+S) i_t(x) \end{cases} \tag{3}$$

where $i_r(x)$ and $i_t(x)$ are backward and forward radiative fluxes, respectively; K and S are the Kubelka-Munk absorption and scattering coefficients, respectively.

After solving the equations (3) with following conditions:

$$\begin{cases} \left(\frac{J}{I}\right)_{x=0} = R \\ \left(\frac{J}{I}\right)_{x=\infty} = R_\infty \\ \left(\frac{dr}{dx}\right)_{x=\infty} = 0 \end{cases} \tag{4}$$

where $I(x) = i_r(x)$**;** $J(x) = i_t(x)$**;** $r = \frac{J(x)}{I(x)}$ we have [9]:

$$\begin{cases} S = \frac{1}{bd} \ln\left[\frac{1-R_d(a-b)}{T_d}\right] \;\; ; \;\; K = S(a-1) \\ a = \frac{\left(1+R_d^2-T_d^2\right)}{2R_d} \;\; ; \;\; b = \sqrt{(a^2-1)} \\ \mu_a = \frac{K}{2} \;\; ; \;\; \mu_s = \frac{-\ln T_c}{d} - \mu_s \;\; ; \;\; g = 1 - \frac{(\mu_a + 4S)}{3\mu_s} \end{cases} \tag{5}$$

In other words, the optical parameters μ_a, μ_s, g can be calculated by backward scattering R_d, forward scattering T_d and transmitted light T_c that in turn, can be measured by double integrating spheres technique (Fig. 1).

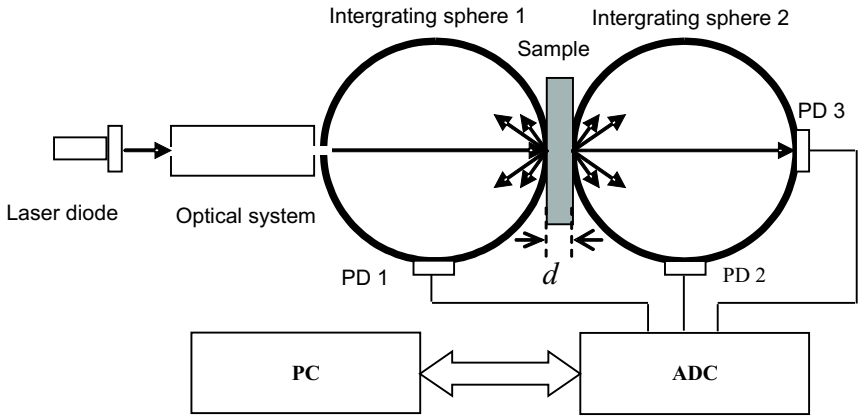


Fig. 1. Block diagram of the aquaculture water checker.

The quantities R_d, T_d, T_c are detected by the photodiodes PD1, PD2, PD3, respectively. Once digitalized by ADC, the signals are sent to PC for processing and evaluating the average values of μ_a, μ_s, g.

The aquaculture water checker is composed with the following main blocks: light source, optical collimator system, double integrating spheres, sample cuvette, ADC converter and processing PC.

The light source consists of laser diode module sld102 (wavelength of 820nm and output power of 20mW) manufactured by the Laser Component company and control modules with over-current, over-temperature protection circuits. The laser output power is kept unchanged by an appropriate feedback loop, colliminated by a well-designed optical collimator system, the light is then oriented into the first integrating sphere.

The double integrating spheres are used to simultaneously collect the backward and forward scatterings. The backward scattering, forward scattering and transmitted light are detected by hybrid photodiodes OPT101 manufactured by the BURR-BROWN company.

The theory on integrating spheres shows that an integrating sphere can be specified by five main parameters: radiance L, sphere multiplier$M$, reflectance ρ, impulse response τ and port fraction f. These parameters are related to each other by the following formulae [10]:

$$L_S = \frac{\phi_i}{\pi A_S}\, M; \quad M = \frac{\rho}{1-\rho\,(1-f)} \quad ; \quad \tau = -\frac{2}{3}\,\frac{D_S}{c}\,\frac{1}{\ln\overline{\rho}} \tag{6}$$

In standard applications, the sphere multiplier $M$is usually chosen in the range of $10 < M < 30$.

The double integrating spheres are designed to meet the condition of M= 30 and the sphere's size as small as possible. In order to do this, a 3D graph representing the

dependence of the sphere multiplier on the reflectance and the port fraction and the plane $M = 30$ are sketched (Fig. 2).

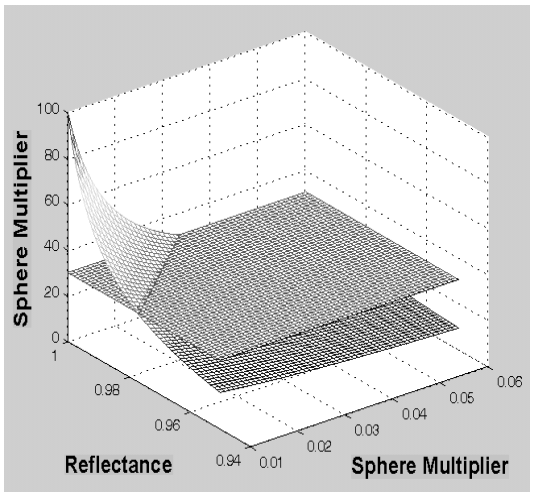


Fig. 2. Relation between the sphere multiplier, reflectance and the port fraction.

The intersection line between the two graphs gives allowed values of reflectance and port fraction:

$$\begin{aligned} 0.977 < \rho \leq 1 \\ 0.01 < f < 0.032 \end{aligned} \tag{7}$$

With the used wavelength 820nm, to meet the conditions (7), the material Spectralon with $\rho = 0.985$ at 820nm is selected (Fig. 3).

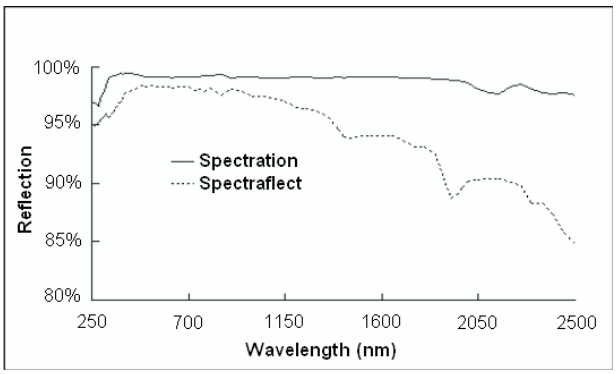


Fig. 3. Relation between the reflection and the wavelength and the material

The total area of input and exit ports are calculated by:

$$S_1 = \pi \left(r_1^2 + r_2^2 + r_3^2 \right) \tag{8}$$

where r_1, r_2, r_3 are radiuses of input and output ports, respectively.

With laser diode beam diameter of 2mm, photodiode diameter of 8,5mm, cuvette path length of 10mm, the total area of the port openings for the two spheres are $S_1 = 138\ mm^2$ and $S_2 = 192\ mm^2$ and their diameters are:

$$37\ mm < D_{s1} < 66\ mm; \quad 44\ mm < D_{s2} < 78\ mm$$

As characteristic of the spheres (illuminance and impulse response) depends on the sphere's diameter, thus, for the R_d, T_d, T_c not being affected by the diameter's difference, two integrating spheres are designed with the same diameter: $D_s = 50\ mm$ (with 5% of tolerance).

The corresponding impulse response, τ, is then nearly equal to 7,35ns and enables the double integrating spheres to work with light modulation frequencies up to 136MHz. In our measurement, the sampling rate is less than 100Hz, thus, the as-designed integrating spheres are suitable for the experiment.

III. MEASUREMENT

The commonly used standard samples in this kind of measurement are diluted milk solutions with various concentrations. Table 1 lists the measured results with different milk concentrations.

The dependences of R_d, T_d, T_c on milk concentration are shown in Fig. 4.

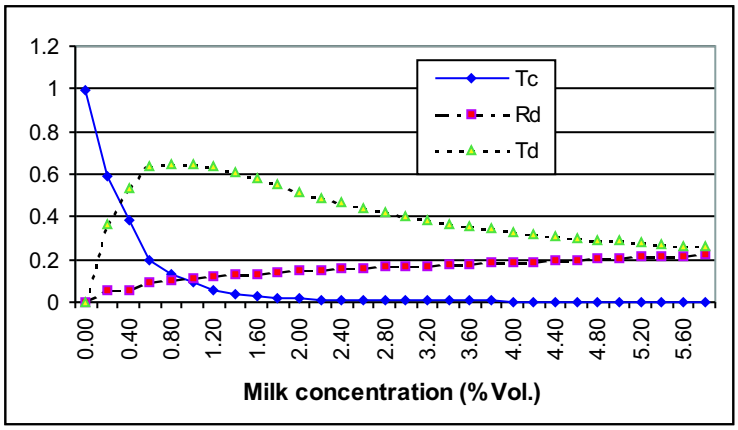


Fig. 4. The dependence of R_d, T_d, T_c on milk concentration

With increasing milk concentration, the T_d attains its maximum value of 0.65 at the milk concentration of about 1% Vol., and then decreases gradually, while R_d get increasing by and by to a saturated value for milk concentrations larger than 5% Vol.. As forT_c, it is decreased exponentially and get negligible at about 3% Vol. concentration.

The optical parameters μ_a, μ_s, g can be evaluated from the measured values R_d, T_d, T_c. Figure 5 shows the dependences ofμ_a, μ_s, g on milk concentration.

Table 1. Average values of R_d, T_d, T_c with different milk concentrations

Concentration (%Vol.)	T_c	R_d	T_d
0.00	0.9958	0.0001	0.0041
0.20	0.5886	0.0600	0.3702
0.40	0.3875	0.0600	0.5351
0.60	0.1986	0.0930	0.6403
0.80	0.1297	0.1018	0.6502
1.00	0.0944	0.1100	0.6501
1.20	0.0543	0.1192	0.6373
1.40	0.0362	0.1285	0.6125
1.60	0.0274	0.1341	0.5821
1.80	0.0181	0.1398	0.5502
2.00	0.0142	0.1455	0.5203
2.20	0.0108	0.1501	0.4881
2.40	0.0093	0.1563	0.4692
2.60	0.0078	0.1604	0.4454
2.80	0.0064	0.1645	0.4243
3.00	0.0064	0.1686	0.4031
3.20	0.0054	0.1717	0.3832
3.40	0.0054	0.1768	0.3683
3.60	0.0054	0.1814	0.3563
3.80	0.0049	0.1850	0.3446
4.00	0.0044	0.1886	0.3325
4.20	0.0044	0.1907	0.3227
4.40	0.0044	0.1953	0.3134
4.60	0.0039	0.1989	0.3017
4.80	0.0039	0.2020	0.2924
5.00	0.0039	0.2082	0.2876
5.20	0.0039	0.2112	0.2785
5.40	0.0039	0.2143	0.2717
5.60	0.0034	0.2190	0.2676
5.80	0.0034	0.2220	0.2615

One can see that the checker enables us to measure milk samples with the concentration lower than 5% Vol.. Furthermore, when the milk concentration is larger than 5% Vol., the μ_a and μ_s values are nearly the same as reported in [11]. In this region, the quantitiesμ_a, μ_s and g reach their saturated values at $4.5 \pm 0.2\text{mm}^{-1}$, $55 \pm 2\text{mm}^{-1}$ and 0.97 ± 0.01, respectively,

After testing the checker with standard milk samples, we also carried out measurements for some aquaculture water samples with isolated Psexdo-Nitzschia-delicatissium algae at various densities. According to the World Health Organization, when algae density presented in the water resources reaches to a certain value, the water becomes seriously

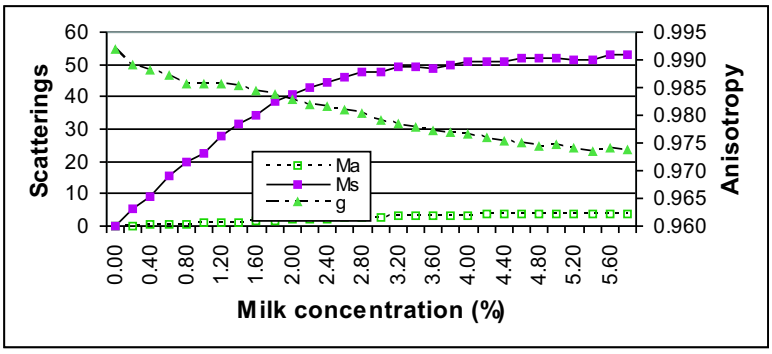
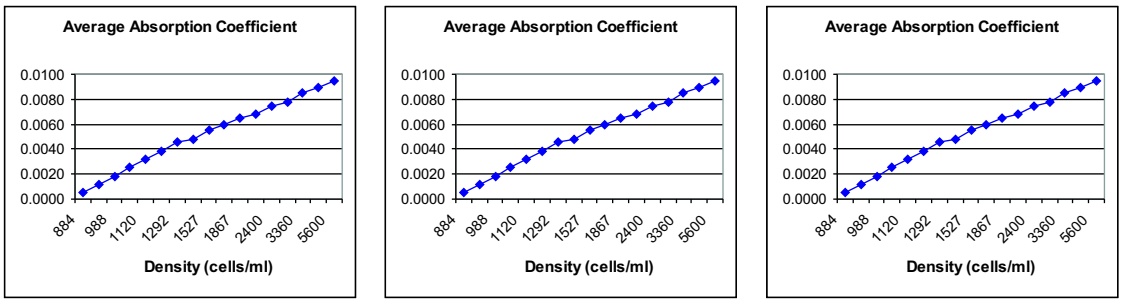


Fig. 5. The dependence of μ_a, μ_s, g on milk concentration.

polluted [12]. Therefore, the investigation of the water resources with low density of algae is very important in water monitoring systems. Figure 6 depicts the dependence of μ_a, μ_s and g on Psexdo-Nitzschia-delicatissium algae density.



(a) (b) (c)

Fig. 6. Dependence of μ_a, μ_s, g on the density Psexdo-Nitzschia-delicatissium algae.

The measured results for the algae samples show that:

The forward scattering in the samples must be predominant due to the fact that the anisotropy is larger than 0.99 for the considered algal concentration range;

Absorption and scattering coefficients are rather small for the considered algal concentration range;

The checker could be used to measure optical properties of aquaculture water samples with algal densities even lower than thousand cells per ml.

IV. CONCLUTION

The real-time, mobile aquaculture water checker is designed and manufactured based on Kubelka-Munk model and double integrating spheres technique. It could be used to measure characteristic optical parameters such as absorption coefficientμ_a, scattering coefficient μ_s and anisotropy g for standard milk samples with concentrations lower than

5% Vol. In the milk concentration range above 5% Vol., the obtained results are in good agreement with other related works. This checker could also be used to measure characteristic optical parameters for aquaculture water samples with algal densities lower than thousand cells/ml.

Nevertheless, in order to meet in-situ measurement conditions, some improvements, such as minimizing weight, integrating a LCD display and specific software in a unique main board, are in progress and will soon be reported.

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