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Optimization of the fluorometric method for determining oil slicksthickness on water surface

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Abstract: Oil slicks thickness can be measured by using such physical processes as Raman scattering and fluorescence radiation at test points on water surface. As a result of the investigations, the optimal mode of measuring the oil slicksthickness with a fluorescent method was calculated. This method provides selecting test measurement points at which, according to the preliminary forecast, an oil slick of a higher thickness is expected to exist at high values of salinity indication. As mentioned above, this order of test points selection will allow to achieve high reliability of measurement results for all test points.

Key words: Oil slick, fluorescence, measurement system, optimization, water salinity.

I. INTRODUCTION

Determination of oil slicks thickness on the sea surface is the most important task to investigate the polluted marine environment. Information on the oil slicksthickness is important for determining the process of temporal and spatial change in theseslicks state. To measure the oil slickthickness on the water surface, such physical processes as Raman scattering and fluorescent radiation can be used.

It should be noted that, the idea of using laser-induced backscattering of Raman was proposed in [1] in 1976 by Kung and Itskan. In 1979, in work [2] Visser proposed using laser-induced fluorescence to measure oil slickthickness on the water surface. Before the presentation of the proposed optimization technique for a fluorescent method to measureoil slicksthickness, theoretical foundations of this method are briefly described. According to [3], the intensity of the induced fluorescent radiation is proportional to the intensity of the exciting laser radiation. At the same time, the intensity of fluorescent radiation increases with slick thickness risinguntil this thickness exceeds the penetration depth of provoking radiation. The penetration depth of arousing radiation increases with wavelength increasing in the ultraviolet and visible ranges.

II. HEADING

According to [3], while fluorescent measurements of the slick thickness are being carried out by the effects of secondary fluorescence radiation, as well as the effects of light scattering in water and in oil slicks, it can be neglected. When a parallel monochromatic laser beam hits intensity I0, fluorescent signals are generatedby means of both the oil slicks and the substances dissolved in the water at oil slicksthickness d.

In this case, the intensity of the total fluorescent signal is determined as follows [3]:

$$I_f(\lambda_0,\lambda_f)=I_d(\lambda_0,\lambda_f)+I_w(\lambda_0,\lambda_f) \tag{1}$$

where: I_d (λ_0, λ_f) are the intensities of the fluorescent signal from oil slick thickness d;
I_w (λ_0, λ_f) are the intensities of background fluorescent radiation from dissolved substances in water;
λ_0, λ_f are the wavelengths of arousing and fluorescent radiations.

According to [3], output signal of the recording detector of the measuring device can be represented in the following form:

$$I_f(d)=B[1-\exp(-A\cdot d)]+C\cdot\exp(-A\cdot d) \tag{2}$$

$$WhereB = f_1(I_0,\lambda_0,\eta_r,T_0,k_0,k_f);\ A=f_2(k_0,k_f);\ C=f_3(I_0,\lambda_0,\eta_w,\lambda_f,T_0,C_0,C_f).$$

Where I_0 is the intensity of the arousing radiation; $\eta_r$is spectral efficiency of crude oil fluorescence at wavelength λ_f; T_0 is the transmission coefficient at air-crude oil boundary; k_0, k_f are attenuations of crude oil at wavelengths λ_0 and λ_f, relatively; η_w is the spectral efficiency of background fluorescence. C_0, C_f are coefficients of water attenuation at wavelengths λ_0, λ_f, relatively.

III. Realization

In Fig. 1 shows a block diagram of the installation used to make measurements

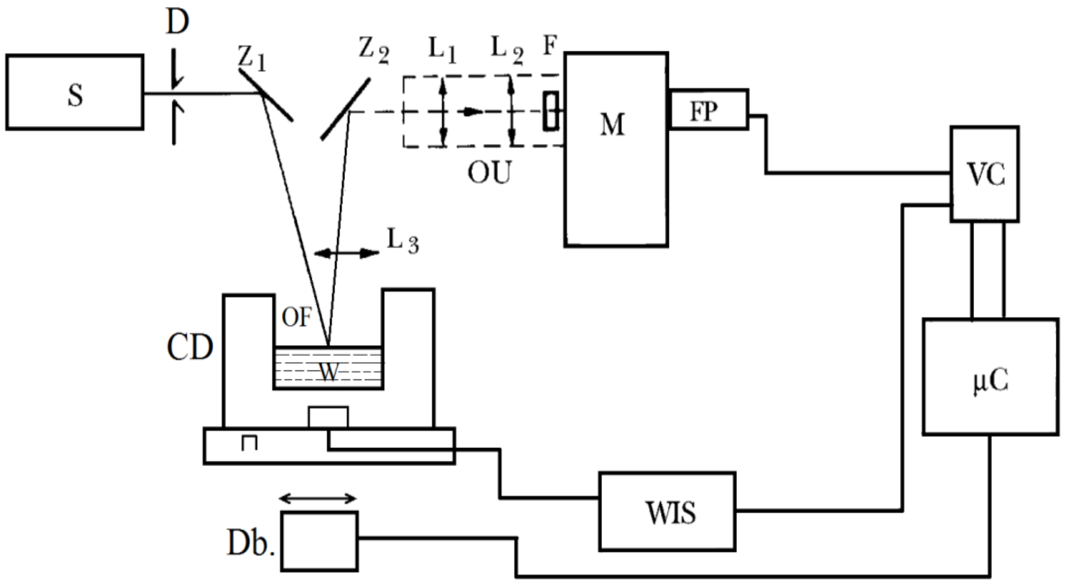

Fig.1 Block diagram of oil slicks thickness measurement system. S is laser radiation source (λ_0 = 632.8nm, He-Ne laser); D is the diaphragm; Z_1, $Z_2$are mirrors; CD is the shifted vessel; OF is an oil slick; W is water; L3 is focusing glass; L_1, $L_2$are the optical systemlenses; F is an absorption filter; M- a monochromator; FP is photomultiplier; VC is digital voltmeter; Db is an engine; P is traveling platform; V is digital voltmeter; µC is a microcomputer; WIS is the synchronization node.

EXPERIENCE

Fig. 2 graphically shows themeasurement results of slick thickness D for different degreescase of solutes presence in water characterized by a salinity indication S.

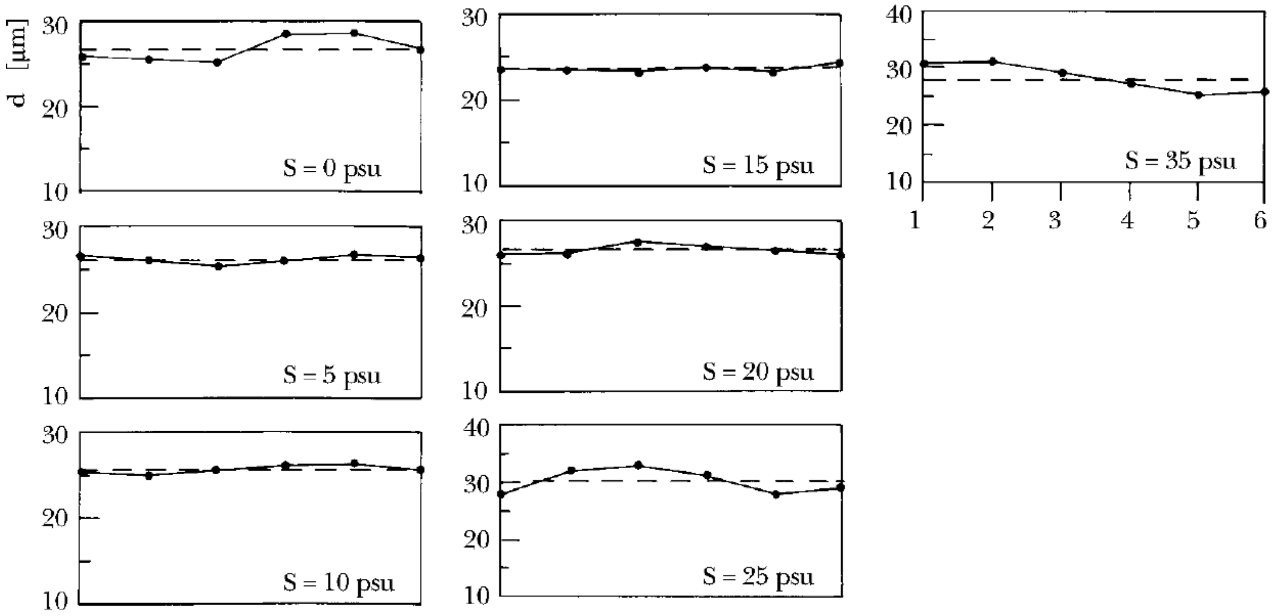

Fig. 2 Graphical representation of the results of measuring slick thickness d at six different points, at different levels of dissolved substances presence in water, characterized by a salinity indication (S), varying within S = 0 - 35 psu [3].

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OPTIMIZATION METHODIC

Let’s state the proposed technique to optimize the procedure for fluorescence measurements of oil slicks thickness. The purpose of the conducted optimization is to determine such optimal form of dependence.

$$d = d(S)_{opt} \tag{3}$$

under the which the functionaldependence

$$I_{f.n.} = \int_0^{S_{\max}} \{B[1-\exp(-A\cdot d)] + C\cdot\exp(-A\cdot d)\}dS \tag{4}$$

would have achieved the maximum value. Consequently, the solution of this problem would enable the selection of such test points with a known value of S_i, $i = \overline{1,n}$; n is the number of test points at which value$d_i$provides the functional dependence (3) according to a preliminary prediction.

In this case, integral value of the measured signal (4) would achieve a maximum value, i.e. the measurements would give the most reliable results.

Certain restrictive conditions imposed on the function (3) were formulated to solve this optimization problem on the base of measurement results processing carried out in [2].

The calculation results of the total values d for all the investigated points are presented in table 1.

Table 1

Points	1	2	3	4	5	6
$\sum_{i=1}^{6} d_i$	186 мкм	190 мкм	183 мкм	189 мкм	184 мкм	182 мкм

As it can be seen from the data presented in table1, the calculated values $\sum_{i=1}^{6} d_i$ are very close to magnitude and differ only by ± 1.35%.

This circumstance allows us to formulate the following restrictive condition imposed on the function d (S)

$$\int_0^{S_{\max}} d(S)dS = C_1 \tag{5}$$

Taking into account equations (4) and (5), as well as functional dependence

$$C = C(S) \tag{6}$$

functional of unconditional variation optimizationis formulated.

$$I_0 = \int_0^{S_{\max}} \{B[1-\exp(-A\cdot d(S))] + C(S)\exp(-A\cdot d(S))\}\cdot dS + \lambda\int_0^{S_{\max}} d(S)dS \tag{7}$$

where: λ is the Lagrange multiplier.

According to Euler method, optimal function d (S) must satisfy the condition

$$\frac{d\{B[1-\exp(-A\cdot d(S))] + C(S)\exp(-A\cdot d(S)) + \lambda\cdot d(S)\}}{d(d(S))} = 0 \tag{8}$$

Taking account into equations (7) and (8) we obtain the following equation:

$$B\cdot\exp(-A\cdot d(S))\cdot A - C(S)\cdot A\cdot\exp(-A\cdot d(S)) + \lambda = 0 \tag{9}$$

By equation (9) the following equation is obtained:

$$d(S) = \frac{1}{A}\ln\frac{A\cdot C(S) - B\cdot A}{\lambda} \tag{10}$$

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To calculate value λ, it suffices to put equation (10) under the integral in formula (5), to perform the integration and determine value λ. In order to avoid expounding unnecessary details of mathematical transformations, the calculated result is denotedas λ0. In this case, as it can be seen from equation (10) for B> C (S), value λ_0 turns out to be negative. Hence, optimal function d $(S)_{opt}$ can be expressed as follows:

$$d(S)_{opt} = \frac{1}{A}\ln\frac{B\cdot A - A\cdot C(S)}{|\lambda_0|} \qquad (11)$$

If decreasing character of dependence of C (S) on S is taken into account, we can conclude that,function d = d $(S)_{opt}$ is a growing function of S. In this case, the second derivative analysis

$$F_1 = \frac{d^2\{B[1-\exp(-A\cdot d(S))] + C(S)\exp(-A\cdot d(S)) + \lambda\cdot d(S)\}}{d(d(S))^2} \qquad (12)$$

shows that for B> C (S), F_1 is a negative quantity, i.e. functional (7) achieves its maximum value for the optimal function (11).

CONCLUSION

Therefore, the optimal mode of measuring oil slicks thickness by the fluorescent method involves the selection of such test measurement points, in which, according to the preliminary forecast, high oil slicks thickness is expected to be at high values S. As mentioned above, this selection order of test points will enable to achieve high reliability of measurement results for all test points.

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