OIL RESIDUALS IN THE SEA: COMPARISON ITS OPTICAL FEATURES WITH OPTICAL PROPERTIES OF THE SEAWATER

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Abstract

Growing intensity of marine transport results in the increase of the amount of oil pollution released into the sea water. The presence of oil in the sea, which is thought to have come from accidental spills or tanker disaster, is connected mainly with the daily operation of marine engines. Pollution from ships engines, can reach the sea water masses together with ballast or bilge water as the result of human error or a failure of marine equipment.

This paper is focused on a comparison of the optical properties of marine waters and oil substances. These include the spectra of absorption coefficient, spectra of scattering coefficient and scattering phase-function (for different wavelength) which describes an angular distribution of scattered light intensity in the sea water. The light scattering phase function depends on the water constituents like mineral suspensions, zooplankton and phytoplankton cells, gas bubbles or so-called yellow substances as well as oil droplets of water pollution.

Detection of oil substances in the sea can be effective when it is done remotely, from ships, buoys, inshore or offshore towers, the decks of aircraft or satellites. The knowledge of the listed above properties of natural (clean) seawater is necessary, because they determine the field of light coming out from the sea and allow interpret images of sea surface from point of view of crude oil and the petroleum products detection. In this study we also discuss optical contrast of oil residuals in the sea in various sea regions.

Keywords: *marine transport, oil slicks, seawater, inherent optical features, sea surface imaging.*

1. Introduction

The total amount of goods transported by sea is steadily growing. This means increasing the number of vessels operating on the seas and oceans, implying a threat of oil products entry to the seawater. The presence of oil in waters, which is thought to have come from accidental spills or tanker disaster, is connected mainly with the daily operation of marine engines. Pollution from ships engines, can reach the sea water masses together with ballast or bilge water as the result of human error or a failure of marine equipment.

Knowledge of the optical properties of marine waters and the optical properties of petroleum substances, that can form in-water emulsions, is necessary to detect and identify the latter in seawater. The clean sea water optical properties determine the water leaving radiation, which provides the background for the signals affected by petroleum products. The remote sensing is the only way to effective detect of oil substances in the sea. It can be provided from ships, buoys, inshore or offshore towers or the decks of aircrafts or satellites.

2. Inherent Optical Properties (IOPs)

Marine optics researchers distinguish two groups of optical properties of medium. The first group forms the Inherent Optical Properties (IOPs) that describe its optical features regardless to external light conditions or the sea surface state. The latter group is called the Apparent Optical Properties (AOPs) and there belongs these quantities, which depend on both optical features and external conditions like the sun position, clouds, sea rougheness, depth (or height over the sea surface) on which the measurements are made and other. The AOPs like water leaving irradiance, irradiation reflectance or remote sensing reflectance can be measured quite easily, but their values are not directly connected with sea water constituents. The sea water composition can be obtained from the analysis of inherent optical properties.

The set of inherent optical properties, which completely describe the propagation of unpolarised light beam in the medium consist of the absorption coefficient and the Volume Scattering Function. The volume scattering function describes the relative amount of light scattered at angles θ deviate from the original beam. This is defined as the intensity of scattered light dI referred to the product of the scattering volume dV and the illumination E of that volume:

$$VSF(\theta,\lambda) = \frac{dI(\theta,\lambda)}{E(\lambda)dV} \, . \tag{1}$$

The definition of the spectral absorption coefficient a can be formed by the decay of the radiance L on the pathlength r:

$$\frac{L(r,\lambda)}{L_0(\lambda)} = e^{-a(\lambda)\cdot r} \, , \tag{2}$$

where:
L_0 - primary radiance.
$L(r)$ - radiance after passing through the distance r in the medium.

Therefore the inversion of the absorption coefficient is a pathway at which the radiance passing through decreases e times.

The integral of the VSF over the total solid angle gives the quantity called the scattering coefficient, traditionally signed as b. Similar integration over the backward hemisphere gives so-called backscattering coefficient b_b. And ratio of b_b over b is the relative backward scattering coefficient. These quantities, which can be calculated from the volume scattering function, together with the absorption coefficient, describe the penetration of light in sea depth and the water leaving signal.

The sum of the absorption coefficient and the scattering coefficient gives the attenuation coefficient c according to $a + b = c$. Total attenuation of the propagating light beam is the result of both absorption of light (which causes the conversion of radiance energy into its another form) as well as the light scattering (which describes the change of direction of propagating light).

3. Methods

Both the VSFs and the absorption coefficients of the clean sea water were measured during the cruise at the r/v *Oceania* in May 2006. The measurements of the volume scattering functions were made with the prototype of Multispectral Volume Scattering Meter (MVSM) described by [3]. Measured functions were partly presented by [1]. Using of the MVSM gave the possibility to measure functions for four wavelengths of visible range 443 nm, 490 nm, 555 nm and 620nm. The absorption coefficient spectra come from measurement made during the same cruise with the ac-9 meter (WetLabs Inc.). Both the VSFs and absorption coefficient were used by [2] to produce a parameterization of an analytical Fournier-Forand function.

The volume scattering functions and the absorption coefficients of oil in water emulsion comes from modeling based on the measurements of refractive indices of oil and water creating the emulsion as well as the measurements of absorption coefficient of crude oil (made by Otremba 1999). For optical properties of emulsion the Petrobaltic crude oil, which is mined from Baltic seabed, was chosen. Calculations based on the Mie model were prepared. The model is an analytical solution of the problem of electromagnetic wave scattering on the spherical particles suspended in non absorbing medium. Modeling gave the angular characteristics of the volume scattering functions prepared for wavelengths 440 nm, 490 nm, 550 nm and 620 nm. These values were chosen as the closest to the wavelengths of measured sea-water VSFs, cause needed spectra of refractive indexes and absorption coefficients of crude oil were measured by with 10 nm step (see [6]).

4. Results and discussion

The volume scattering functions of oil-in-water emulsions and sea-water are presented in Fig. 1. They were plotted for four different wavelengths of visible light range. It may be noted that the range of variation of both the emulsion and sea-water functions is over five orders of magnitude. For small angles, regard to primary beam of light, the scattering is the highest and falls rapidly for bigger angles. The graph of seawater VSF shows the minimum values in the range from 120 to 150 degrees (see Fig. 1b) and a slight increase in the backward directions. While the VSF of oil emulsion (see Fig. 1a) is characterized by a local increase in the value for scattering into perpendicular angle region and much higher increase in the backward directions than seawater. The smallest values of the VSFs are observed for angles from 120 to 130 degrees. Similar view of the oil-in-water light scattering phase functions were presented by [5]. Spectral variability of the oil emulsion VSF does not change strongly with scattering angles. Short-wavelength scattering predominates over scattering for longer wavelengths. For open sea water the spectral variability of the VSF is less evident, especially for small angles. However the extension of the middle angle range reveals that for 90 degrees angle area the long-wavelength scattering predominates. For higher scattering angles the spectral variation is dominated by shorter wavelengths.

a)

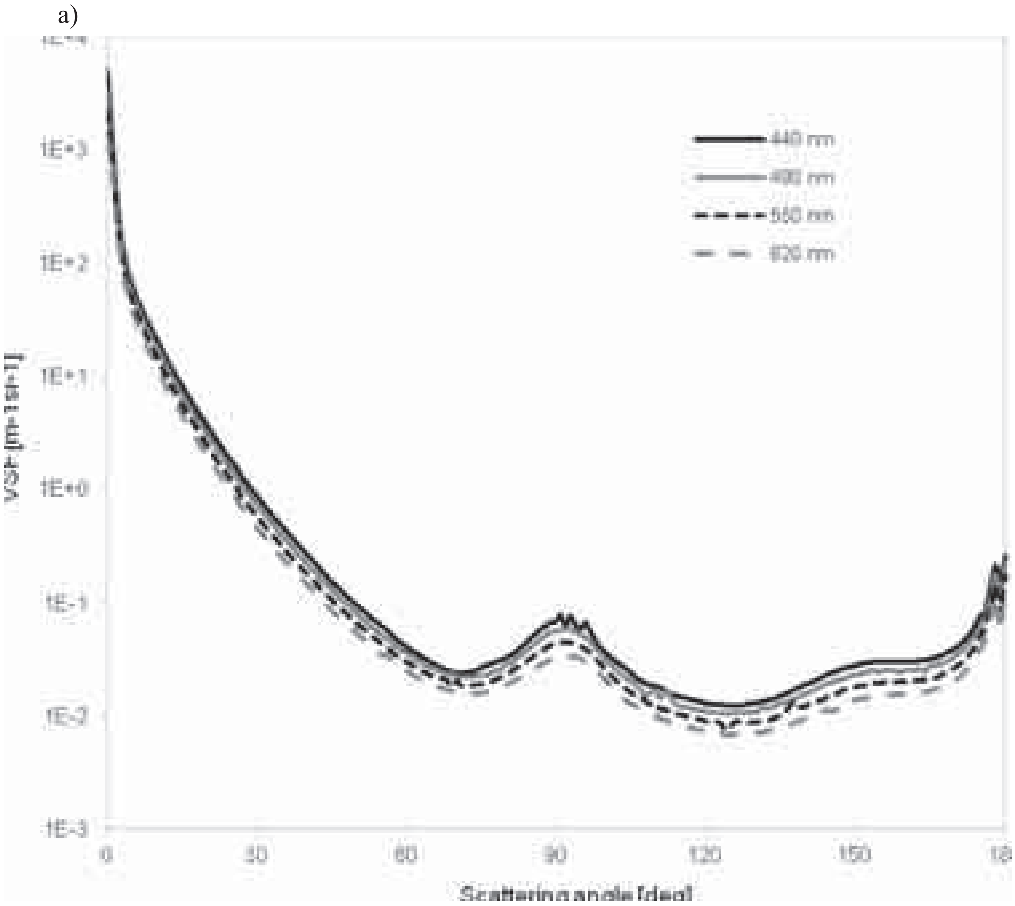

Fig. 1a. The volume scattering functions for oil-in-water emulsion

b)

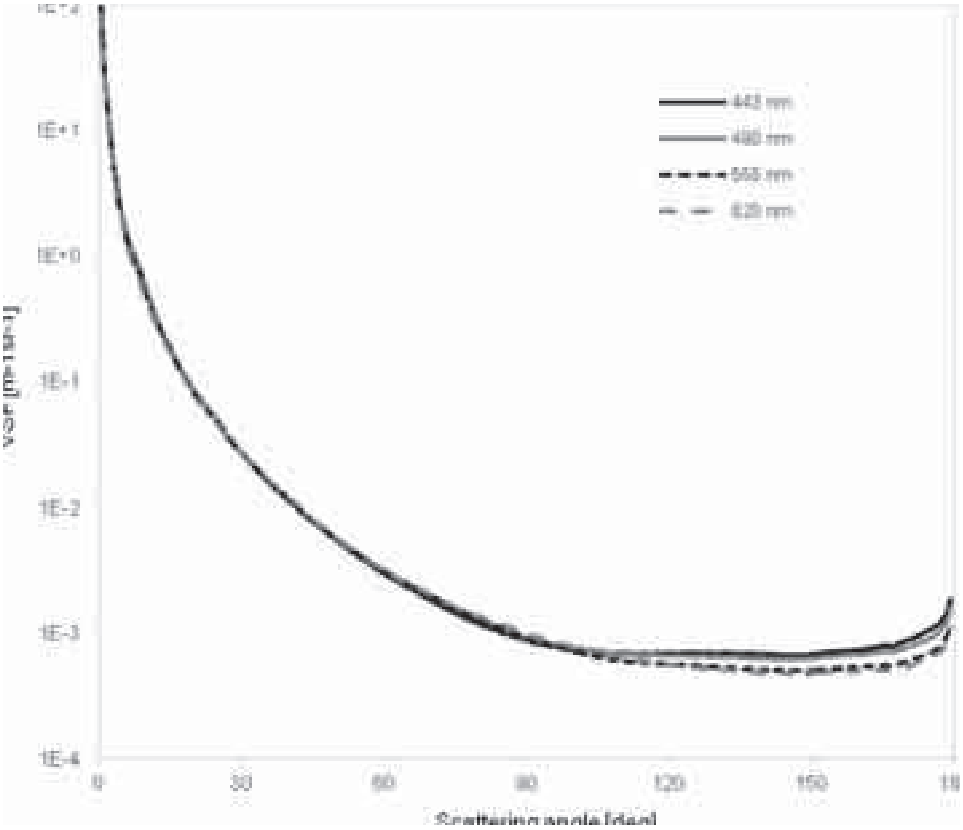

Fig. 1b. The volume scattering functions for open waters of Baltic Sea

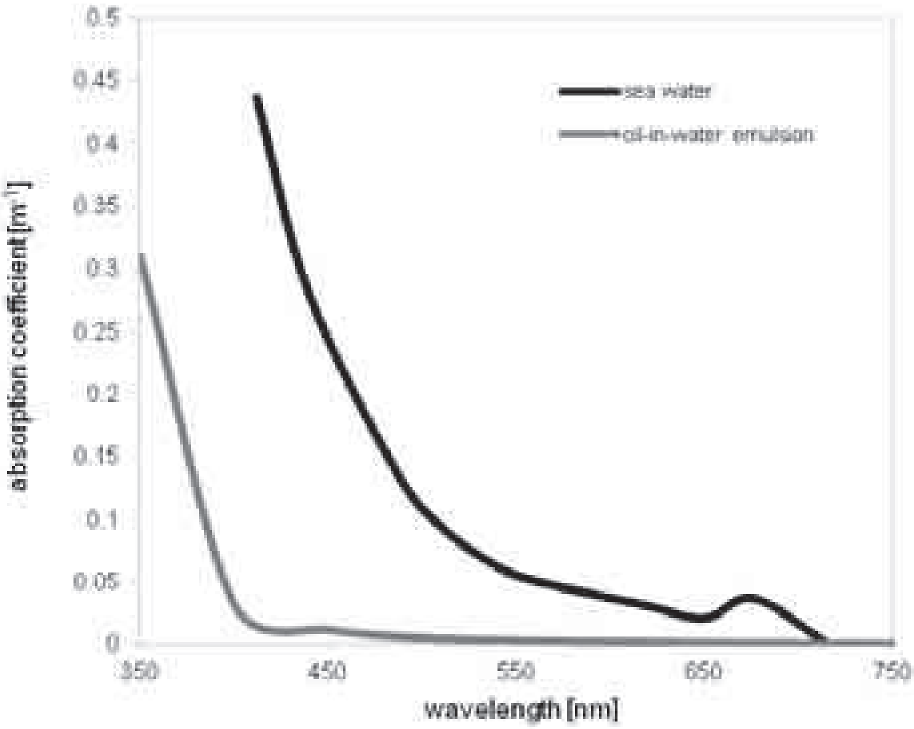

Fig. 2. The spectra of absorption coefficient of open Baltic Sea water and oil in water emulsion

The spectral variation of the absorption coefficients reveals strong absorption in short-wavelength spectral range for both oil-in-water emulsion as well as seawater. However the absorption coefficient of emulsion drops rapidly for wavelengths shorter than 400 nm and is almost flat for the rest of visible light range. The author of [4] shows that the spectrum of oil in water emulsions depend on the type of oil. While the absorption of open sea water decreases slower with growing wavelength and reaches its minimal value for about 650 nm. Higher wavelengths reveal small increase, which is characteristic for phytoplankton spectra.

Summary

The comparison of inherent optical properties of open Baltic Sea water and the emulsion of oil mined from the Baltic seabed reveals some characteristic differences in their spectral or angular characteristics. The VSFs of oil in water emulsion have characteristic increase for each wavelength in the perpendicular scattering angle area. While VSFs of seawater show that in the same region the spectral inversion of characteristic occurs. Absorption coefficients differ clearly in their spectra. For emulsions the spectrums falls rapidly for short wavelengths and is almost flat for others, while seawater spectrum reveals slower decrease with wavelength and the small maximum in the red light region.

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