OPTICAL PROPERTIES OF FUELS AND LUBRICANTS VS. AQUATIC ENVIRONMENT PROTECTION ISSUES

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Abstract

Oils can be optically described by two parameters: light absorption coefficient and light refraction coefficient. Spectrum of absorption coefficient manifests itself in colour of oil, whereas spectrum of refraction coefficient impacts on both refractive and reflective properties of interface between oil and surroundings. Both spectra of absorption coefficient and refraction coefficient have distinctive slopes in ultraviolet edge of spectrum where values of mentioned coefficients decrease from extremely high in ultraviolet to relatively low in visual range. Possibility of perceiving of oil existing in the form of thin film or in the form of an emulsion depends on ambient light conditions and on mentioned optical properties. Additionally perceiving of oil depends on thickness of the oil film and on type of substrate on which oil is spread (water, metal etc.), as well as - if emulsion oil-in-water or water-in-oil is considered - on the droplets size distribution. The present paper begins with a review of optical properties of several oils. Next, an impact of changes of those properties on optical properties of an oil film (spread on water) as well as an impact of those properties on optical properties of oil-in-water emulsion is explained. Finally, exemplary results of numerical simulation of light transfer in marine environment (using above optical properties) – e.g. angular distributions of optical contrast of both sea areas clean and polluted by an oil-film are presented.

Keywords: *oil film, fuels, lubricants, aquatic environment protection*

1. Introduction

Qualitative requirements to petroleum products are focused mainly to the temperature characteristics of coefficient of viscosity and density, durability and resistance to degradation (in relation to lubricants), as well as calorific value and low content of substances harmful to the engine (applies particularly to fuels). All these properties are characterized by clearly defined measurable physical quantities which are listed in product specifications. However during storage and operation process the quality parameters of petroleum products may deteriorate, which can externalize in colour and transparency. Therefore in some cases, the optical properties may be regarded as a simple indicators of specific operational characteristics of the substance - especially in difficult conditions (i.e. marine environment), where full laboratory test equipment is not available. So far, no accurate comparative study on the applicability of the optical properties of oils as the proxies of specific operational properties has been conducted.

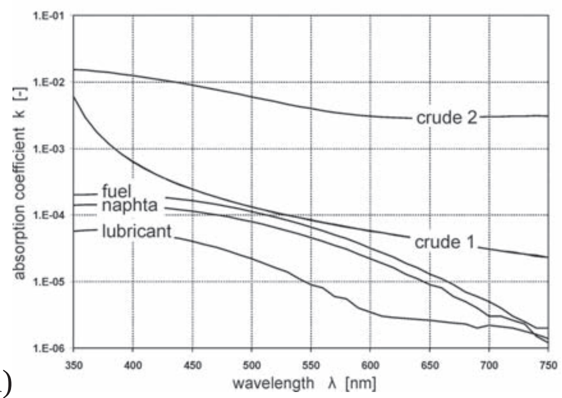
Within the issues related to the optical properties of oil is the problem of marine environment protection (against such substances), which is placed in several research fields, e.g.:

- detection of petroleum refinery products and other petroleum derivatives (generally referred to as “oil”) in the water discharged into the sea,
- remote detection of oil in the sea environment,
- identification of the perpetrator of an oil discharge.

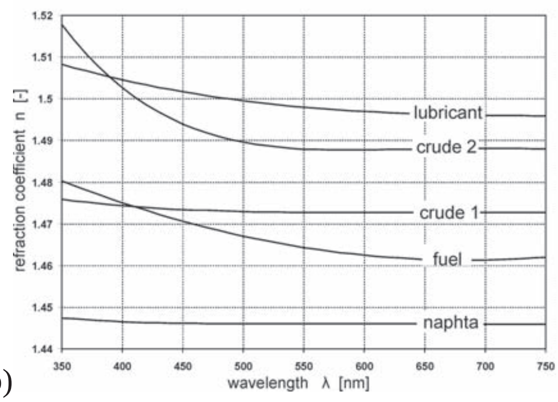
In this paper we present fundamental properties of chosen types of petroleum refinery products, including fuel and lubricant. An essential consequence of those properties is phenomenon of optical contrast of oil slicks on the sea surface. The issue of the contrast of marine areas polluted by oil is extensive and not fully solved yet. However recently the number of works on this subject has increased [1-5], but in fact operational methods of detection of oil in the sea using satellite optical sensors do not exist yet! Only in the case of huge catastrophic spillages satellite surveillance can be efficient [6]. Knowledge about the effects in the optical properties of the sea posed by oil and natural components of sea water is very poor. However, the optical control of marine oil pollution with the use of moving cameras in the lower atmosphere commonly operates [7]. There is even some professional equipment to detect oil on water surface, but at close distances only [8]. In further parts of this paper various related to the oil optical phenomena and possible applications are presented.

2. Spectra of optical properties of oils

In Fig. 1 we present two fundamental optical properties of chosen oils – spectra of absorption coefficient and spectra of refraction coefficient. Trying to parametrically describe the differences in the shapes of spectral waveform of optical properties of various oils slopes of waveforms was determined in the short-wave range of the spectrum. Averaged slope in the range of 450-550 nm (between blue and green) in the Fig. 2 are shown. Values of these slopes are closely associated with a subjective vision of the colour of oil. This is a proposition of practical indicator of how the subjective feeling of oil colours can be represented objectively, i.e. with a single parameter (absorption at 450 nm divided by absorption at 550 nm).



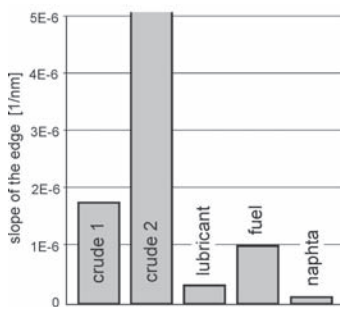
a)



b)

Fig. 1. Fundamental optical properties of oil: spectra of absorption coefficient (a) and spectra of refraction coefficient (b)

a)



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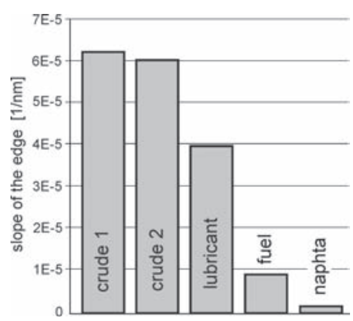

Fig. 2. Diversity of slopes of edges of spectra of absorption coefficient (a) and refraction coefficient (b)

3. Optical properties of oil vs. optical properties of oil film

Interaction of light with the oil film is a complex phenomenon but electrodynamic model for a thin layer on the substrate is enough to describe it [9]. If the oil film on water is considered, then for a specific wavelength, up to four angular dependencies must be used to characterize optical properties of such film, namely: transmissivity and reflectivity for light running from the atmosphere to the water and transmissivity and reflectivity for light running from the water to the atmosphere. In Fig. 3, angular waveforms of transmissivity and reflectivity for the blue and green light running from top to bottom are shown, while in Fig. 4 are similar courses but for light running from bottom to top. It is worth noting that if the oil film is spread on a metal surface, the directional dependence of reflectance is quite different than if the same film is spread on the water surface (Fig. 5).

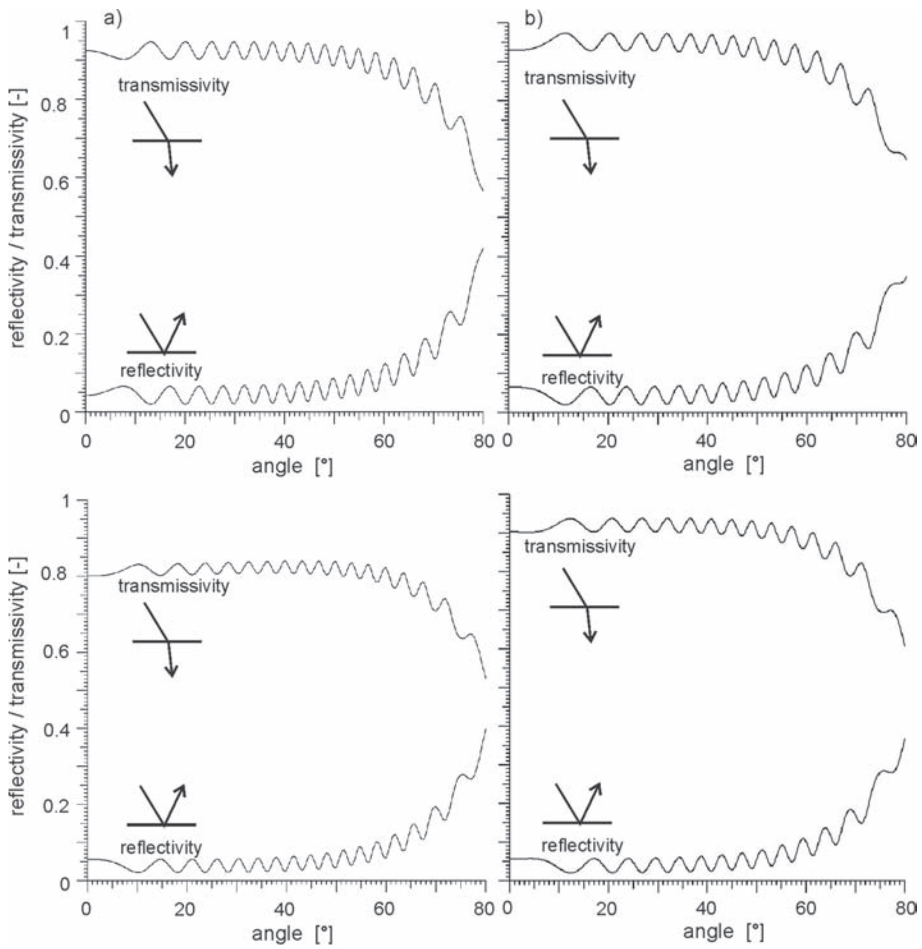

Fig. 3. Angular dependencies of reflectivity and transmissivity for oil-film (of 10 μm thickness) spread on water, for down-running light, made with exemplary lubricate oil (upper) and exemplary fuel oil (lower), for 450 nm (a) and 550 nm (b)

4. Contrast of oil slicks

The appearance of an oil spill on the water surface depends primarily on the type of oil (on its optical properties), the thickness of the film, lighting conditions, optical properties of the sea water and on direction of observation. Just this dependence of visibility (contrast in relation to clean marine area) on the direction of observation was determined by computer simulation [1] and presented in Fig. 6.

5. Discussion

Graphs in Fig. 6 show the final results of modelling of contrast of oil slick on the sea surface. In this modelling - which in fact is computer simulation of a very big number of photons tracks in marine environment - the optical properties of the oil (Fig. 1) were necessary as the input data. These are the results of exemplary modelling, in which apart from the optical properties of oil are included other data, like: oil thickness (10 μm), the direction of incidence of sunlight (perpendicular), the state of the surface (no wind) and the optical properties of sea water (typical for the coastal zone). Because so many factors affect the contrast of oil slick, results above shown should be regarded only as an example of the possibility of establishing an objective relationship between visibility of oil slick and fundamental optical properties of oil.

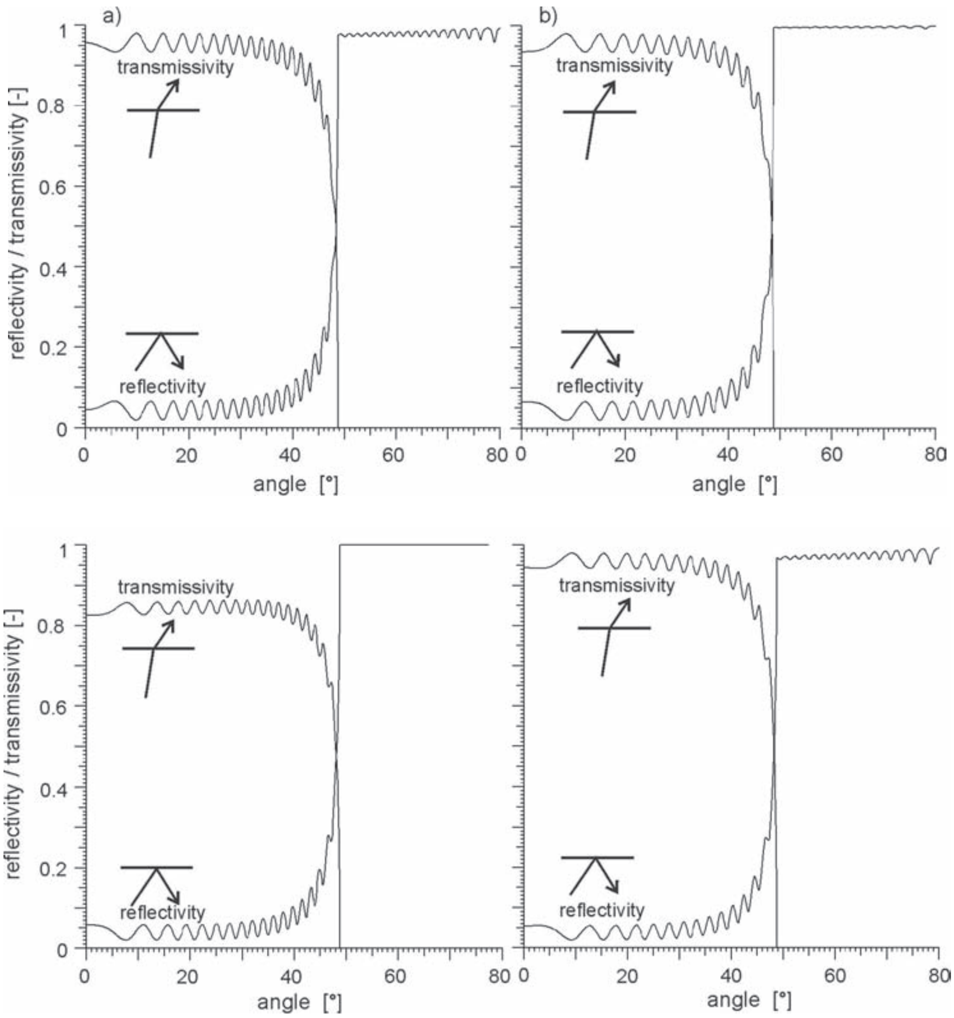

Fig. 4. The same as in Fig. 3 but for up-running light (from water to atmosphere)

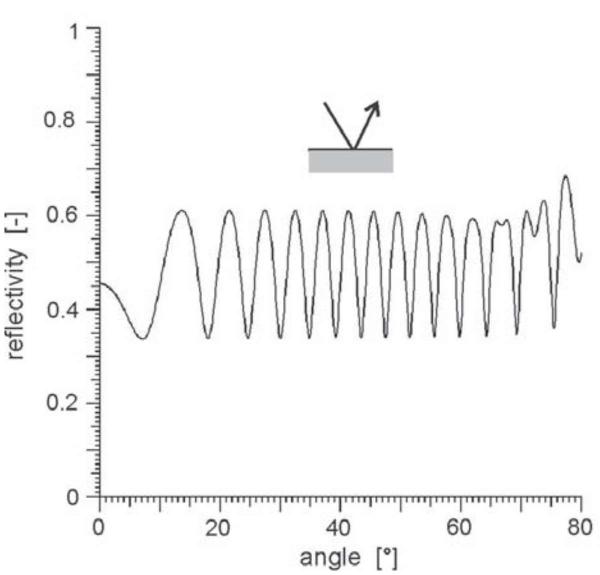

Fig. 5. Angular dependencies of reflectivity of light, when oil film of 10 μm thickness made with exemplary fuel oil spread on metallic (steel) substrate

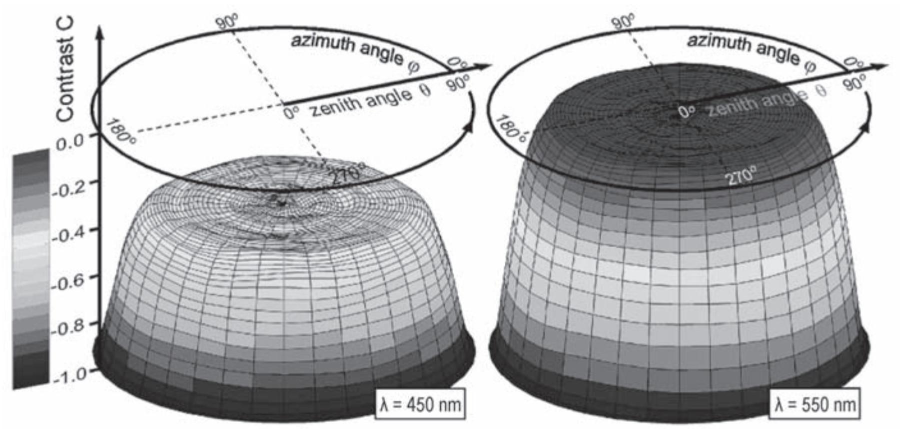

Fig. 6. Angular distribution of contrast of an oil film spread on calm sea-surface for two bands of wavelengths: 450 nm (blue) and 550 nm (green)

Another example of usefulness of fundamental optical properties of oil is prediction of analogous as in Fig. 6 dependence, not for oil slick, but for oil dispersed in the water column. In such case optical properties of oil are used to determine optical properties of oil-in-water emulsion (then oil droplets size must be advised also).

Knowing the optical properties of oil, there is possible prediction of reflectivity for oil film, spread on a specific substrate, as a dependence on wavelength, film thickness and angle of incidence of light (example in Fig. 5 is shown).

As for other applications, the existing knowledge allows describing the optical properties of oil emulsion and can be used in designing nephelometric device for measure of oil content in oil-in-water emulsion or water content in water-in-oil emulsion.

Moreover, if the basic optical properties of other than oil substances will be determined the same way as for oil, their share in the optical properties of emulsions and films can be used.

Theories of both interactions of light (with film and with emulsion) take into account the polarization of light. Thus, in this case, one can expect that by fundamental optical properties of oils diversity, it will be possible to determine the consequences of this diversity in relation to the polarimetry techniques.

The stage of research of phenomena mentioned in this article is differential. However, as above indicated examples show, knowledge of fundamental optical properties of oil moves to the possibility of determining the course of numerous of optical phenomena in which oil takes part.

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