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COEFFICIENT OF LIGHT REFLECTION FORESEEN FOR CHOSEN OILS

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Abstract

Properties of oil substances manifest themselves by numerous physical, chemical and physicochemical parameters. Among various physical parameters (like temperature dependencies of the density or the friction coefficient), optical parameters can be underlined, namely: coefficient of light refraction and coefficient of light absorption, both as dependencies on the light wavelength. Those parameters are only primary optical characteristics of define substance, because in fact they constitute input data for example in the calculation other optical waveforms like light reflection coefficient (reflectivity), which can be useful in techniques in which oil plays any role. Reflectivity is a value in electrodynamics theory when the light is treated as an electromagnetic wave and can be derived from Maxwell equations for the plane wave which incidence the air-oil interface.

The main assumption of this study is expectation that reflection of the light from the surface of define oil contain spectral information about features of oil. In this paper, there are presented spectral dependencies of reflectivity for the light which incidents the surfaces of various examples of oil, namely: crude oil Romashkino, lubricate oil Marinol, fuel oil L-1. Such information can help in the future in preparation the remote (touchless) method of detection the quality of define exploitive oil substance or changes of its properties.

Keywords: *oil, reflectometry*

1. Introduction

Qualitative properties of crude oils or oil-refinery products are expressed by physically defined measurable quantities (listed in product specifications). During storage or transport as well as during operation process the quality parameters of oil deteriorates, which may be manifested in its colour and transparency. Therefore, it seems that the optical properties may be applied as indicators of specific operational characteristics of the substance.

The spectrophotometry and spectrofluorometry are relatively popular optical procedures for characterization interaction between light and matter. Optical manifestation is also included in light refraction coefficient or reflection coefficient as a function of light wavelength. If reflection coefficient is considered – we have the surface demarcating oil and air in mind.

In this paper, studies on angular dependencies of reflection of the monochromatic light from interface air-oil are described.

2. Method

Electromagnetic theory of the light in connection with electron theory of electric conductivity explain phenomenon of light reflection when optical properties of the medium change (wave reflection on the boundary of two media) [1, 2]. In a theory both speed of the light and absorption of the light are factors influencing light reflection. Those parameters are mathematically represented by purely abstractive value called "complex refraction coefficient", (CRC, *m*):

$$m = n + ik \,, \tag{1}$$

where:
m – complex refraction index
n – real part of complex refraction index, coefficient of refraction, light speed in vacuum per light speed in the medium
k – imaginary part of the complex refraction index, nondimensional absorption coefficient
i – imaginary unit.

The name "complex refraction coefficient" (CRC) contains expression "refraction coefficient" as a result replacing n (in theory of light transfer in dielectric medium) by m (in theory of light transfer in conductors). In fact, every medium is conducting material, but in lower (isolators) or greater (metals) scale. It means, that no material with reflection coefficient equal zero. Reflection is strictly connected with possibility to electric conductivity and on the other hand – between conductivity and light absorption relationship exists.

The real part of CRC is measurable value – refraction coefficient (RC, n). Refraction coefficient was in this study measured by means of Abbe's refractometer in stabilised temperature using monochromator to measure in various light wavelength.

Imaginary part (k) of CRC is derived from measurable value – absorption coefficient a – by means following relation (2):

$$k = \frac{a\,\lambda}{4\,\pi}, \tag{2}$$

where:
λ – light wavelength,
a – absorption coefficient (dimension: 1/m).

Absorption coefficient of oils was measured using spectrophotometer Specord Carl Zeis Jena in quartz 1 mm cuvette.

Algorithm for derivation of reflection coefficient as a function of angle of light incidence came from solution of Maxwell equations for plane electromagnetic wave fouling on medium (oil) characterized by complex refraction index [2, 3].

3. Results

In Fig. 1 two fundamental optical properties of chosen oils are presented, namely: spectra of refraction coefficient (upper chart) and spectra absorption of coefficient (lower chart). Both coefficients are nondimensional as relatively real and imaginary part of above described complex refraction index.

Using classical electromagnetic theory for plane wave reflection on air-oil interface, reflection coefficient for seven light wavelengths were derived (like previously for absorption and refraction). Reflection coefficient for perpendicular direction of light incidence varies from 0.0381 to 0.0399 for crude oil, from 0.0391 to 0.0401 for lubricate oil and from 0.0359 to 0.0361 for fuel oil. In every case reflection coefficient increases with angle of incidence. Nevertheless, from 0^o to 10^o reflection coefficient holds itself on stabile level.

4. Discussion

A fundamental question is how reflection coefficient (further expressed by acronym REFL) of oil depends on refraction coefficient (REFR) and on absorption coefficient (ABS). If REFR of are considered, its values increases relatively in order: fuel – crude – lubricant. At the dame time REFL increases in the same order. Therefore it seems that REFL increases when REFR increases. Therefore, arises a question if REFL depends on ABS. Unfortunately no explicit answer; because ABS of studied oils increases in order different like REFR, namely fuel – lubricant – crude.

Therefore other tests were performed, namely dependence of REFL separately on REFR (where ABS is constant) and on ABS (REFR constant). At the analysing of dependence on REFR the value of ABS was equal to value typical for oil substance. Analogously when dependence on ABS was analysed – REFR was also equal to value characteristic for oils.

(a)

(b)

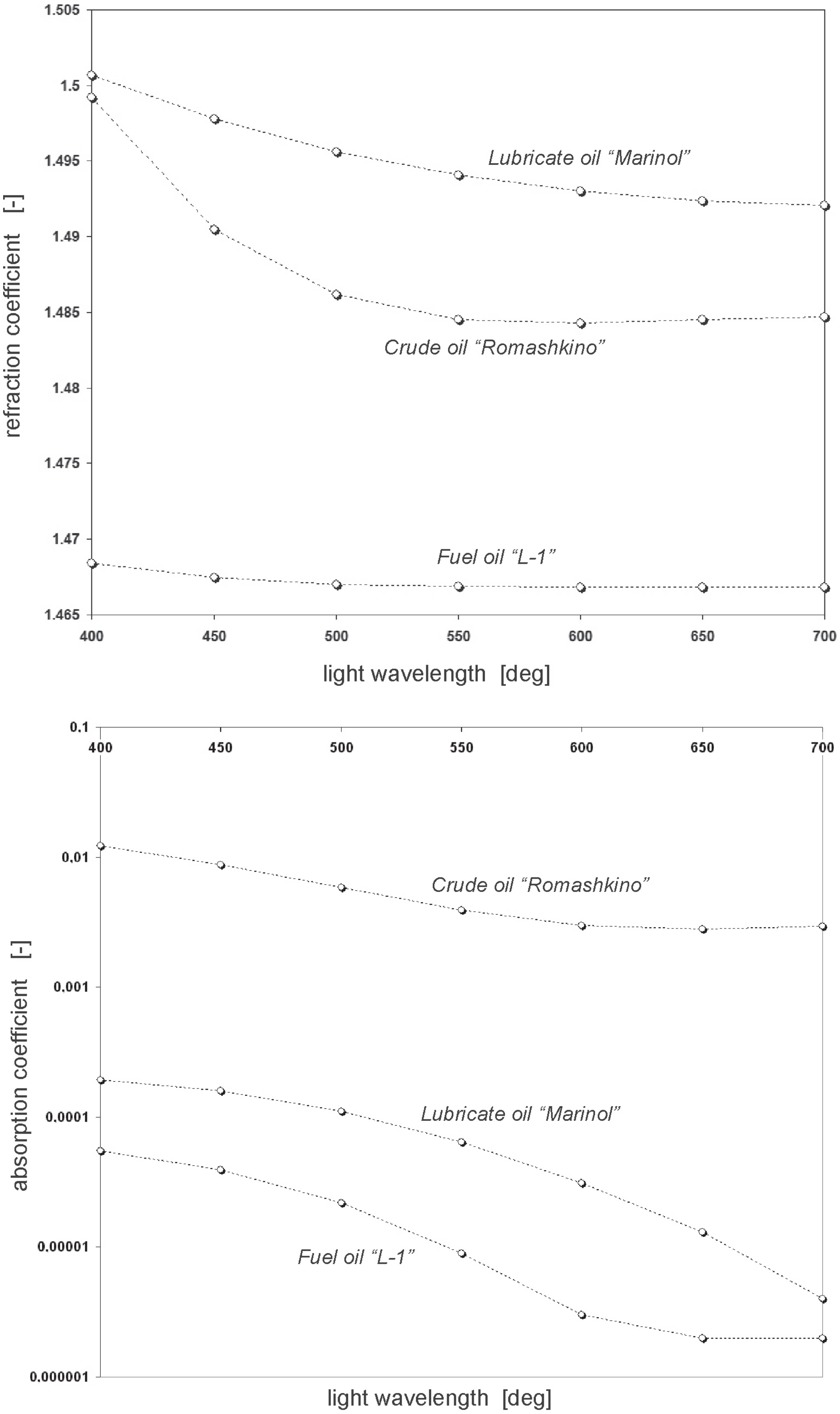

Fig. 1. Fundamental optical properties of oil: spectra of refraction coefficient (a), spectra of absorption coefficient (b)

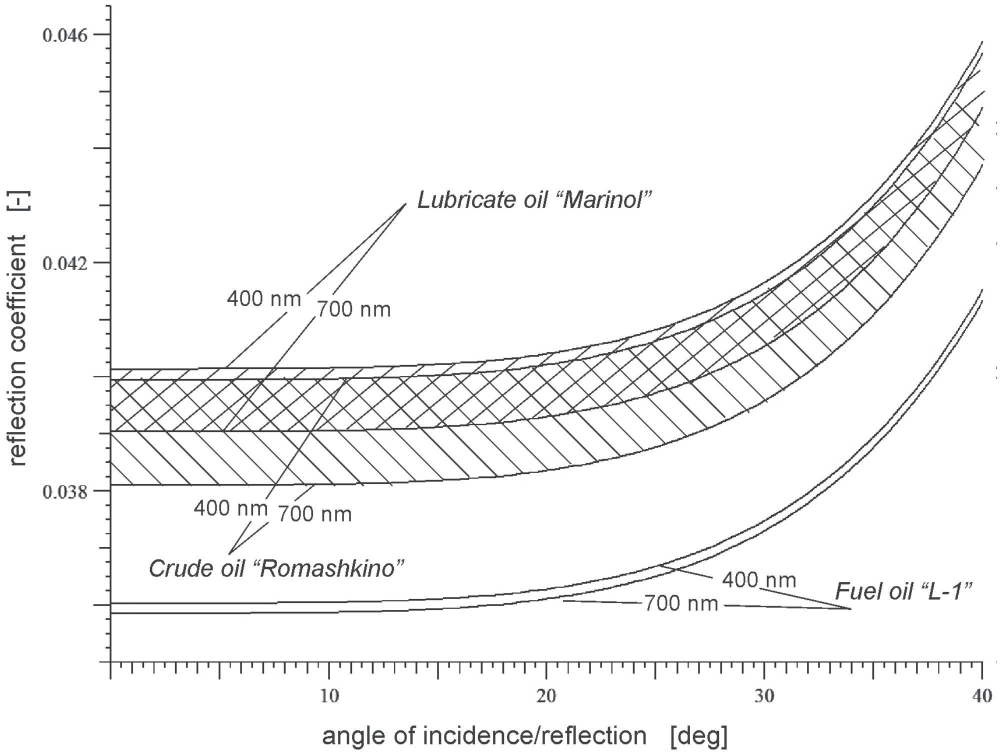

Fig. 2. Reflection coefficient as a function of an angle of light incidence for various wavelengths (from 400 to 700 nm)

There was stated that increasing of REFR results in increasing of REFL as Fig. 3 shows. For direction of light incidence closed to perpendicular (0^o) REFL for various oils is approximately two times greater than for water. On the other hand when ABS increases REFL increases also (Fig. 4). However, in the scale of possible ABS variability for various oils no noticeable changes of REFR. Notwithstanding noticeable changes are visible for other than oil substances, which characterize itself considerably greater ABS. Those substances are for example metals. Very efficient in this case is silver. Absorption coefficient – ABS for metals is the real value but cannot be measured using methods acceptable for light transparent substances as if oils are. From classical physical point of view high ABS is accompanied with high electrical conductivity. This statement is connected with Drude free electron theory of metal conductivity (theory over 100 years old). In experimental physics there is known the scientific field named “reflectometry” to determine various features of the matter using optical methods. There is a chance that also light reflectance on the air-oil interface can produce information about oil features. Anyway, as predicted in the here presented study, from measurement of light reflection in various wavelengths from define oil, one could determine spectrum of refraction coefficient of oil. Unfortunately reflectometry cannot bring information about nondimensional absorption coefficient (symbol k in relation (2) and consequently its derivative value, which is dimensional absorption coefficient (symbol *a* in relation (2).

Possibility of the reflection coefficient computation for air-oil border, when both refraction and absorption coefficients as input data are applied, is demonstrated in this paper. Solution of the inverse problem – identifying of both refraction and absorption coefficients (REFR & ABS) on the base of reflection coefficient (REFL) – cannot be performed from mathematical point of view; nevertheless, one can predict that if the accordingly wide database of results reached using method described in this paper would be prepared – then automatically selection of adequate for define REFL material parameters REFR & ABS will be possible. In any case, the described here optical method using for oil testing, as a non-invasive, is worthy of attention.

Further question to solve in the future is how the analysing light reflectance of oil covering solids (metal alloys, composites etc.) may provide new data on behaviours such substances in various conditions.

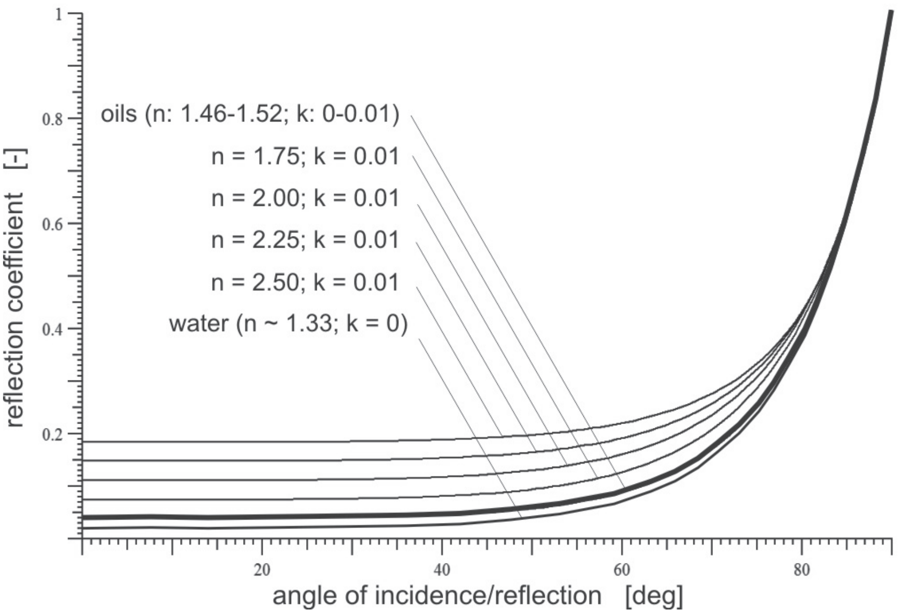

Fig. 3. Reflection coefficient for various hypothetical refraction coefficients at absorption coefficient typical for oils

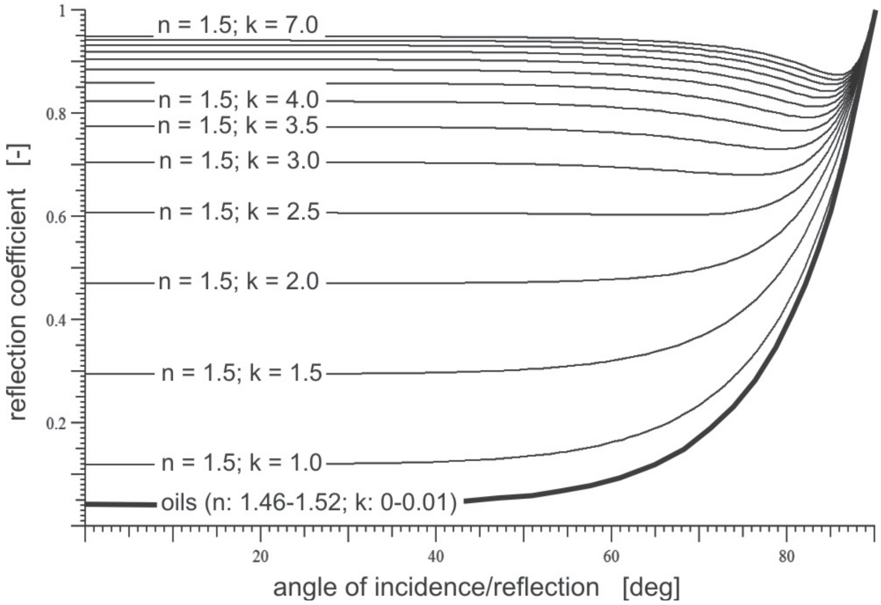

Fig. 4. Reflection coefficient for various hypothetical absorption coefficients at refraction coefficient typical for oils

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