Conference materials
UDC 535.8
DOI: https://doi.org/10.18721/JPM.163.215

Features of monitoring the state of viscous media by refraction

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Abstract. The article grounds a necessity of liquid media control using refractometer. A method for monitoring liquid media, including mixtures, using refractometric measurements is proposed. A system of equations has been developed to determine the composition of the medium, which consists of components that have not reacted chemically. The results of experimental studies are presented.

Keywords: liquid, refraction, refractive index, concentration, light-shadow boundary, media state control

Citation: Bazhanova V.A., Davydov V.V., Features of monitoring the state of viscous media by refraction, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (3.2) (2023) 92–96. DOI: https://doi.org/10.18721/JPM.163.215

Материалы конференции
УДК 535.8
DOI: https://doi.org/10.18721/JPM.163.215

Особенности контроля состояния вязких сред методом рефракции

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Аннотация. Обоснована необходимость контроля жидких сред с использованием рефрактометра. Предложена методика контроля жидких сред, включая смеси, с использованием рефрактометрических измерений. Составлена система уравнений для определения состава среды, которая состоит из компонент, не вступивших между собой в химическую реакцию. Представлены результаты экспериментальных исследований.

Ключевые слова: Жидкость, рефракция, показатель преломления, концентрация, граница свет-тень, контроль состояния среды

Ссылка при цитировании: Бажанова В.А., Давыдов В.В. Особенности контроля состояния вязких сред методом рефракции // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2023. Т. 16. № 3.2. С. 92–96. DOI: https://doi.org/10.18721/JPM.163.215

Introduction

A person who takes care of his/her health [1–3] is constantly thinking about what foods he/she will eat and how it may affect his/her health. To do this, many carry out express control of their health [4, 5]. In the human diet, very popular dishes that require frying on vegetable oil or dishes that add the same oil (for example, vegetable salads). Thanks to the content of vitamin E and unsaturated fatty acids, vegetable oil is healthy for the prevention of atherosclerosis, myocardial infarction and other cardiovascular diseases. The rise in prices for all services and goods has led to a deterioration in the quality of oil for various reasons. The number of oil treatment cycles is reduced, less valuable oils (soy, cotton, rape and others) are brought into sunflower oil, and refined and unrefined oils are mixed with many others. It is very difficult to determine the substitution in such mixtures using express control devices. This is done using chemical techniques or high-resolution spectrometers [6 –9]. This control is possible only in a stationary laboratory. The X-ray rapid monitoring devices developed do not meet the requirements for this task, because the chemical composition and physical structure of the test sample must not change during the tests. This test, in the event of a detected deviation, should be further studied by a stationary laboratory for confirmation. This is especially true in the case of mixing refined and unrefined oil. Unrefined oil contains phosphates, fat-soluble vitamins (A, E, K), waxes, carotene, aromatics and other compounds. Unrefined oil cannot be stored for a long time, quickly becomes turbid and is not suitable for frying unlike refined. The use of such a mixture can lead to great harm to human health.

Currently, a large number of small and mobile refractometers of various types have been developed for express control of various liquid media with an error in measuring the refractive index n to 0.00005 [10 –14]. These instruments operate on the phenomenon of full internal reflection, and their measurement does not take into account a number of features. These features appear both in n measurements and in the composition of the mixture. This is especially true for the study of different oils. Therefore, the aim of the work is to establish these features for edible oils and add-on methods of controlling mixtures of edible oils with new ratios for unique determination of mixture composition of two components.

Features of control of the mixture of edible oils

In the express control of edible oil it is important to take into account one of the features - refinement or unrefinement of oil. This will make it possible to properly process the results in the future to determine the composition of the mixture of two oils and their concentration. To do this, at the place of sampling it is necessary to determine this condition of the oil using refraction. We assume we don't know what kind of oil we're testing, except it's edible. The technique has been developed that allows the refinement of the oil to be determined using two measurements of the position of the light-shadow by using total internal reflection (TIR) and frustrated total internal reflection (FTIR). Measurements to determine the position of the border shadow-light on the frustrated total internal reflection in industrial structures refractometers for express control cannot be realized. Therefore, it will be necessary to use a different design of the refractometer. The unrefined oil contains various components and dyes. Due to the presence of these components, the border shadow-light on the FTIR will be significantly different from the border shadow-light for TIR. In a mixture of refined and unrefined oil, the difference in the structure of light-shadow boundaries will depend on the ratio between the concentrations of these oils in the test mixture. If the unrefined oil is expired, a turbid sediment is formed at the bottom of the bottle. In order not to change the color of the oil, usually drain the top transparent layer and add it to refined or unrefined oil. In the expired unrefined oil, heavy components and dyes fall into the precipitation. Waxes remain in the top layer of oil. The refractive index of wax n_w varies from 1.4445 to 1.4473. The original sunflower oil has a higher refractive index (on the order of 1.46–1.47 depending on the region of production). The top layer of expired unrefined oil will have a lower refractive index than the original expired oil due to the presence of wax. Since the size of the wax molecule in the oil is very small, the light scattering at λ = 589.3 nm will not be [15]. And another way is needed to determine the refinement of the oil and the presence of the component in the test mixture. It is proposed to implement this using the mass equation, because the density of the oil ρ changes when part of the elements precipitate. Also, the density of the oil depends on the degree of its treatment. For different varieties of oil, the value is ρ different. In addition, the value of ρ depends on the temperature T [16, 17]. In this case, can be used a system of two equations (1) to study the oil mixtures: refraction equations and mass equations:

$$\begin{cases} k_1 n_1 + k_2 n_2 = n_{12}, \\ V\left(k_1 \rho_1 + k_2 \rho_2\right) = m_{12}, \end{cases} \quad (1)$$

where n_{12} is the refractive index of investigation mixture, n_1 and n_2 are the refractive indices of the media of which the investigation mixture may consist, k_1 and k_2 are the coefficients that shows the relative content of different media in the studied mixture (if it is necessary to get the percentage content, these coefficients are multiplied by 100%), ρ_1 and ρ_2 are the values of densities of the two media which are contained to investigation mixture (considering the temperature), m_{12} is the mass of the research mixture, V is the volume of the research mixture from which the value of m_{12} is measured.

After solving the system of equations, it is possible to unequivocally determine the composition of the mixture of two edible oils and the concentration of components.

Optical part design of refractometer and experimental results

For implementing the developed technique for studying mixtures from edible oils, was developed a new optical design of mobile refractometer. The feature of the design is the presence of an additional light prism, thanks to which measurements can be made in daylight or artificial light. Also, the advantage of the device is the lack of power from the network, in order to explore a large number of viscous media. Fig. 1 presents the modernization of the optical design of the refractometer, allowing to measure the refractive index of condensed medium with the use of the upper and lower prism.

Fig. 1 presents the case of measuring the value of n_{12} using the TIR phenomenon. For the realization of the n_{12} value measurements using the phenomenon of FTIR cover *5* with mirror *6* closes (light stop entering to prism *1*. The cover *5* opens without the mirror and the light enters the top prism *2*, and also the refractive index is measured at the border of the light-shadow and changes are recorded.

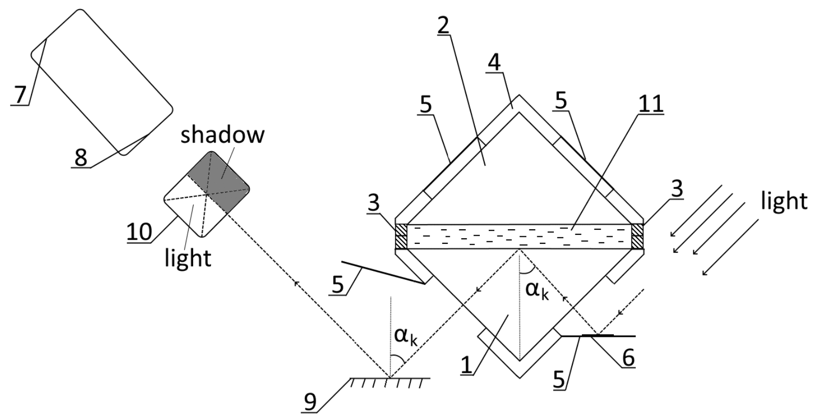

Fig. 1. Schematic diagram of the optical part of the refractometer and ray path for lower prism: lower triangular prism *1* (material leucosapphire), upper triangular prism *2* (material leucosapphire), silicone gaskets *3*, rotating prism mount *4*, closing flap *5*, mirror *6*, eyepiece *7*, lens on movable mount *8*, mirror *9*, plate for registration of the light-shade border *10*, medium under study *11*

In order to confirm the methods developed by us, studies have been carried out on mixtures of different oils. Fig. 2 shows the measurement of refractive index n_{12} of mixture of refined and unrefined oils.

Analysis of the measurements in Fig. 2 shows that the light-shadow border obtained by the TIR method is very different from the border obtained by the FTIR method. The light-shadow boundary is almost blurred. The presence of components in the mixture, which scattering the light, corresponds to the unrefined oil.

In the study of refined oil, the light-shadow boundary is clearer (Fig. 3)

In order to determine the concentration of oils in the mixture, the refractive values of refined and unrefined oils n_1 and n_2, previously measured, were placed into the system of equations (1). The density values ρ_1 and ρ_2 of each oil were also placed into the system of equations. After weighing the sample, in which refined and unrefined oils were mixed in a ratio of 10 ml : 10 ml (V = 20 ml), it is possible to have the value of m_{12}, which is also placed into the system (1):

$$\begin{cases} k_1 \cdot 1.4703 + k_2 = 1.4695, \\ 2 \cdot 10^{-5} \left(k_1 \cdot 800 + k_2 \cdot 890 \right) = 16.9 \cdot 10^{-3}. \end{cases}$$

The solutions to this equation system are the required oil concentration values k_1 = 0.503 and k_2 = 0.497. The obtained values correspond to the proportions in which the refined and unrefined oil were mixed within the measurement error.

a) *b*)

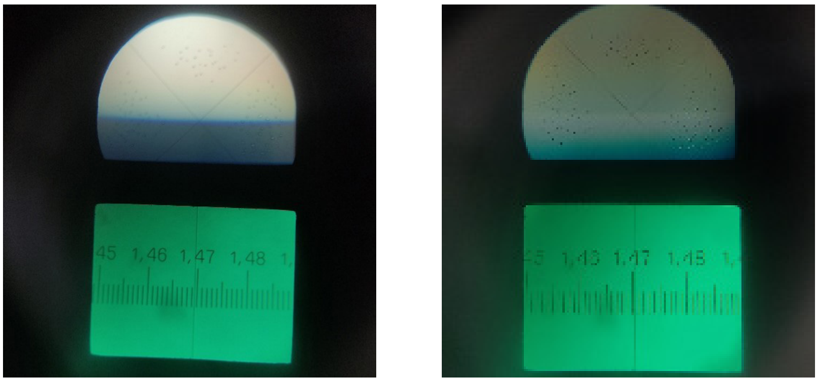

Fig. 2. Measurement of refractive index n_{12} of mixture of refined and unrefined oils using the method of TIR (*a*) and FTIR (*b*)

a) *b*)

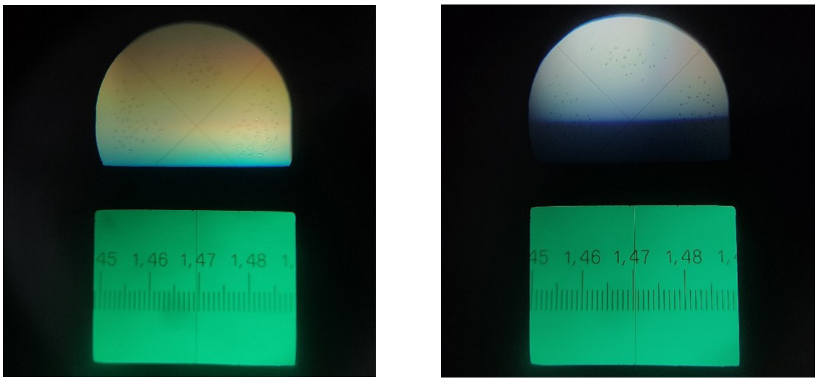

Fig. 3. Measurement of refractive index n_{12} of mixture of refined and unrefined oils using the method of TIR (*a*) and FTIR (*b*)

Conclusion

The analysis of the obtained results shows the adequacy of the technique developed by us for express control. The values obtained from the study on the composition of the oils and the concentrations of the components are the same as the types of oils and their concentrations used for the preparation of the tested media.

Another feature of this method is the dependence on the resolution of the light shadow on the power (or intensity) of the light source in the oil mixture. This factor is also related to the oil concentrations in the mixture and requires separate studies.

Experiments have shown that the upgraded design of the refractometer can also be used to monitor the condition of other medium. It may also be possible to use it to control their mixtures, provided that these media do not react chemically. Of additional interest are liquid degreasing media. This will also be the subject of our next studies.

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Received 14.07.2023. Approved after reviewing 18.09.2023. Accepted 18.09.2023.