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New technique for control of liquid media state by optical method in express mode

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Abstract. The necessity of express control of the state of liquid media in real time is substantiated. Various methods of express control of the state of liquid media are considered. The basic requirements for these methods are determined. An optical method for monitoring the state of liquid media using the phenomenon of refraction is presented. The use of a small-sized differential-type refractometer for express control of the state of liquid media is substantiated. Its design has been developed and a new principle for measuring the refractive index of the investigated liquid has been proposed. The results of experimental studies are presented.

Keywords: Refraction, express-control, laser radiation, liquid, refractive index, differential cuvette of Anderson, medium state

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Материалы конференции
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Новая методика контроля состояния жидкой среды оптическим методом в экспресс режиме

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Аннотация. Рассмотрены различные методы экспресс-контроля состояния жидких сред. Обосновано использование малогабаритного рефрактометра дифференциального типа для экспресс-контроля состояния жидких сред. Разработана его конструкция и предложен новый принцип измерения показателя преломления исследуемой жидкости. Представлены результаты экспериментальных исследований.

Ключевые слова: Рефракция, экспресс-контроль, лазерное излучение, жидкость, показатель преломления, дифференциальная кювета Андерсона, состояние среды

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Introduction

The development of scientific and technological progress has set a large number of tasks for scientists [1–6]. One of which is the express control of the state of liquids in real time [2, 7–11]. Its role in the modern world is very difficult to assess, since the number of negative factors that worsen the state of liquid media is constantly increasing [1, 2, 12–15]. Express control of the state of various media during experiments or in production is especially in demand. Or when conducting environmental monitoring, where there are no automated control systems [16−21] In these cases, it is impractical to use expensive high-resolution equipment that require special operating conditions. To solve such problems, compact, reliable equipment with an autonomous power source is required [8, 12, 13, 16, 21−26]. In addition, ongoing studies of the state of the medium during express control should not change its physical structure and chemical composition [16−21]. This is necessary to obtain confirmation of the detected contamination in the environmental sample on high-resolution instruments in a stationary laboratory. One of the methods that satisfies these requirements is based on the phenomenon of refraction [21–25, 27, 28]. The refractive index of the medium n and the temperature T are measured. And the value of n is compared with the value of n, which corresponds to the standard state of the medium.

Currently, small-sized refractometers are used for express control of the state of the medium. The principle of their operation is based on the phenomenon of total internal reflection. (TIR) [28−34]. During their operation in various situations, especially in the field (environmental monitoring), a number of problems arise. One of them is related to the provision of the thermal stabilization mode for the measurement process of the refractive index of a liquid medium. It takes a certain time to ensure the required temperature during the measurement. It also requires a certain amount of electrical energy, which is limited by the capacity of the battery. In addition, the dynamic range of refractive index measurements for these devices is not large (usually no more than 0.03 –0.05). Such devices are designed for express control of a certain type of media or food products [30, 31, 34–36]. With strong pollution, the refractive index of the medium changes more significantly (more than 0.1 or 0.2). This will make it impossible to measure n. Uncertainty will arise (device does not work or unknown environment). The paper presents one of the solutions to these complex problems.

The design of a differential refractometer with Anderson cuvette of Anderson and the principle of measuring the refractive index of a liquid medium

In the designs of differential refractometers developed earlier for find the value of the refractive index nm measured angle a. [27, 28, 34, 38]. For measurements in the field, this measurement method turned out to be difficult to implement, since it is necessary to provide accurate measurements of the rotation of optical elements to determine the angle β. When transferring the device, misalignment of the structure is possible. In addition, when measuring the angle β, the temperature T of the environment will affect the operation of the optical elements. This will lead to a large measurement error. Moreover, with this principle of measurement, it is quite difficult to ensure the small size of the design of the refractometer.

Therefore, we have developed a new method for measuring the refractive index n_m of the medium under study. This method is based on the derivation of an analytical equation for determining the shift L of the maximum of laser radiation on a photodiode line from the values of the refractive indices n_s and n_m, the parameters of the Anderson cuvette, and the place where laser radiation is injected into the cuvette. On figure 1 shows the layout of a laboratory model of a differential refractometer with an Anderson cuvette and a photodiode line that we developed.

The distance L, by which the radiation has shifted, the decision on the total displacement at beam refraction when entering the cuvette partition (L_1), when leaving it (L_2), when entering the cuvette wall (L_3) and when leaving it (L_4) (Fig. 1).

$$L = L_1 + L_2 + L_3 + L_4 \tag{1}$$

After carrying out various calculations at the boundaries of two media (reference liquid -

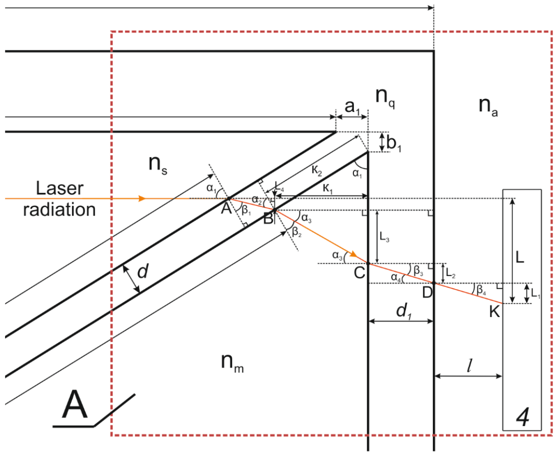

Fig. 1. Scheme of propagation of the laser radiation maximum in the Anderson differential cuvette and in the space up to the photodiode array

quartz, quartz - measured liquid, measured liquid - quartz and quartz-air), the following formula was obtained to calculate L:

$$L=\sin\alpha_1\left(d\left(1-\frac{n_s\cos\alpha_1}{\sqrt{n_q^2-n_s^2\sin^2\alpha_1}}\right)+\left(\sqrt{n_m^2-n_s^2\sin^2\alpha_1}-n_s\cos\alpha_1\right)\right)\times$$

$$\times\left(\frac{e}{\sqrt{n_a^2-\sin^2\alpha_1\left(n_m^2-n_s^2\sin^2\alpha_1+n_s^2\cos^2\alpha_1-2n_s\cos\alpha_1\sqrt{n_m^2-n_s^2\sin^2\alpha_1}\right)}}+\right.$$

$$+\frac{d_1}{\sqrt{n_q^2-\sin^2\alpha_1\left(n_m^2+n_s^2\cos^2\alpha_1-n_s^2\sin^2\alpha_1-2n_s\cos\alpha_1\sqrt{n_m^2-n_s^2\sin^2\alpha_1}\right)}}+ \qquad (2)$$

$$\left.+\frac{K_1}{\cos\alpha_1\sqrt{n_m^2-n_s^2\sin^2\alpha_1}+n_s\sin^2\alpha_1}\right).$$

We introduce the required parameters of the cuvette: width, length, wall thickness of the cuvette – b = 30 mm, a = 40 mm, d_1 = 2 mm, respectively, the thickness of the partition d = 1 mm, the distance from the cuvette to the photodiode bar – l = 30 mm, let the beam at a distance y = 3.0 mm from the top wall of the cuvette.

Let's check the formula (2) in the Matlab environment for the case when n_s = nm. The laser beam is displaced by a distance $L = L_1$, exits the cuvette at a right angle. It turned out the distance L_1 = 0.4365 mm. This is consistent with experimental data.

Results of the study of liquid media and discussion

The experiments performed have shown that the effect of ambient temperature T on the process of measuring nm is insignificant. This is due to the fact that the Anderson cuvette is made of quartz glass (the refractive index of quartz changes insignificantly when the temperature is measured from 276 to 313 K). The linear portion of the change in the dependence $n(T)$ for quartz glass has been very well studied. The value of T is measured with an error of 0.1 K. During long-term measurements, the temperature of all objects, including the liquid medium, stabilizes. In some cases, a thermostat is used in refractometers to stabilize the temperature in the cuvette location area. This is effective for small cuvette sizes.

As an example, figure 2 shows the results of a study of the effect of metal scale in a pipeline on the state of drinking water at various temperatures T. The temperature change was carried out in an Anderson cuvette using a thermal stabilization scheme developed by us for a small-sized model of a differential refractometer (Fig. 1). The results obtained showed the possibility of establishing the presence of metal scale in drinking water by changing the value of n. It should be noted that the nature of the change in $n(T)$ for two media does not change, which means that the measurements are stable. Analysis of the obtained data shows the reliability of the differential refractometer we have developed.

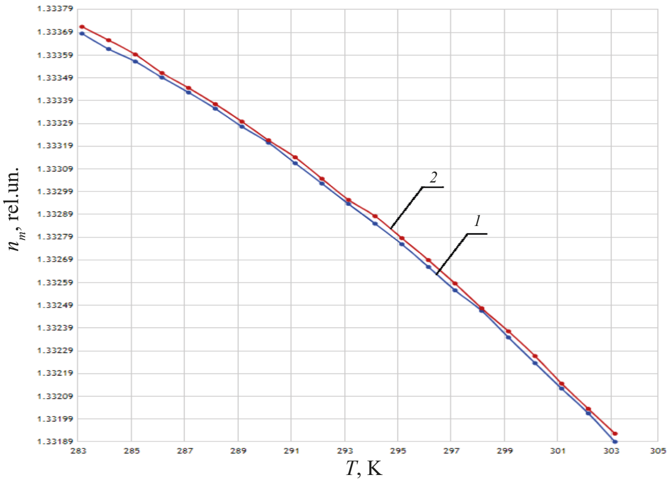

Fig. 2. Dependence of the change in the refractive index nm of drinking water on temperature T.
The graphs correspond to the state of drinking water:
1- there are no oxides in the water, *2*- there are oxides in the water.

It should be noted that the n_m measurement method developed by us makes it possible to set the measurement error depending on the range of n_m variation. For example, in the range of n_m variation from 1.4 to 1.5, using relation (*2*), by selecting the cuvette parameters, the refractive index of the reference liquid n_s and e, one can provide the following measurement mode (a change in the value of nm by 0.0001 corresponds to a shift of the laser radiation maximum by one photosensitive sensor). For measurements is used a photodiode array with 1024 photosensitive sensors (1000 sensors are used to determine L). In this case, the measurement error will be 10^{-4}. Previously, this result was not possible.

Conclusion

The results obtained allow us to consider that the design of the differential type refractometer proposed by us can be used to solve problems of express control of the state of liquid media in various situations. The results obtained by us allow us to consider that the design of the differential type refractometer proposed by us can be used to solve problems of express control of the state of liquid media in various situations. Our measurement accuracy of 0.0001 fully satisfies the strict requirements of express control, including medicines and biological solutions.

It should be noted that the results obtained by us make it possible, on the basis of a differential refractometer with an Anderson cuvette, to develop a first-class verification scheme for measuring the refractive index of liquid media. To do this, under laboratory conditions, for example, for the range of nm in the range from 1.43 to 1.44, it is necessary to provide a change in the value of n_m by 0.00001 to shift the maximum of laser radiation by one photosensitive sensor. In this case, the measurement error will be 10^{-5}, which is very close to the accuracy of the state standard.

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