Features of monitoring the state of the liquid medium by refractometer

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Abstract. The features arising during the control of the state of a liquid medium flow by the registration of light-shadow boundary displacement on the photodiode array are considered. The technique for adjustment of the refractometer optical part was developed in order to ensure the contrast degree not lower than 0.75 for light-shadow boundary during measurement. The results of experimental studies of various media are presented.

1. Introduction

One of actual problems of the applied physics is development of new instruments and modernization of existing instruments for liquid media flow monitoring [1-5]. Nowadays, non-contact methods of measurement have been widely used to solve various problems of liquid flows investigation [3, 6-8]. At the same time methods where the contact with the liquid flow is insignificant are also used. But these methods of measurements demand an additional requirements. They should not make significant changes in the hydraulic resistance of the liquid flow and distort the flow structure. Based on these methods, nuclear magnetic and optical meters of physical quantities of the liquid flow have been developed [6-12].

Studies of flows of aggressive and dangerous media (for example, benzene, heptane, concentrated sulfuric acid, etc.) are the most difficult. Significant problems arise when the measurement requires sterility conditions (for example, biological solutions, medical suspensions, part of food products, etc.) is investigation [13, 14]. Measurements of these flows of liquid media must be done by methods where the direct contact between the measuring elements of the instrument and the medium under study is absent. The conducted studies have shown that applying of some methods create problems with further use of some media. For example, the effect of ultrasonic waves influences negatively on the physical properties of biological solutions, makes a change in the taste of food products, etc. In addition, the liquid flow could contain solid particles and bubbles. In this case large measurement errors appear when using ultrasonic methods. In the case of poorly transparent media, increasing of the laser radiation power also negatively influences on the chemical and physical properties of biological solutions, medical suspensions, etc. Methods for studying the flow of liquid media on the basis of the phenomenon of nuclear magnetic resonance are the most universal [3, 13-15]. Usually, these devices
are quite expensive. Therefore, it is necessary to look for alternative variants. One of these variants is represented in our work. It is a refractometer for monitoring the state of the flow of liquid media.

2. Features of control and experimental setup

In some cases, there is a small contact between the measuring elements of the instrument and the flow of the medium under study. In case of such contact, the following conditions should be fulfilled. The first one is unchangeable structure of the liquid flow. The second and the most important condition is the following. In case of the long contact between the studying medium and measuring elements, chemical composition of the medium under study and physical structure of the medium must not change. In addition, in time of measuring should be provided the sterile condition. The most effective way to solve such problems is the use of optical materials as measuring elements [2, 7, 9, 12, 16]. In refractometers during measurements, the contact of the liquid flow takes place only with one edge of the prism, which is included in optical part of the device. The figure 1 shows the structural diagram of the optical part of the refractometer developed by us.

![Figure 1. Structural diagram of the optical part of the refractometer](image)

Our investigations showed that in case of the design of the optical part of the refractometer developed by us, some special features appear. These features should be taken into consideration in case of studying the liquid medium.

We found that in case of studies of liquid media flows with large insoluble compounds (for example, juice with pulp, medical suspensions, biological solutions, etc.) it is very difficult to measure the refractive index \( n_m \) of the medium. In some cases, for example, a solution of juice with water and pulp, it is incorrect. Therefore, the best way to control the state of the liquid medium in the liquid flow is recording the position of the boundary-light shadow on the photodiode array (figure 1). In this case, it is necessary to calibrate at first the dependence of the light-shadow boundary position on the photodiode array upon the temperature of the medium \( T \) and determine the light-shadow boundary points on the photodiode array corresponding to the standard state of the medium. As compared to other optical methods used to study liquid flows, the position of these points does not depend on the flow velocity. This is one of the features of the medium state control in the refractometer developed by us. Any deviations from the standard state could be fixed with high accuracy by analyzing changes of boundary light-shadow boundary position in case of observing the temperature of the liquid medium.

One more feature in the realization of the medium state control is the position of the laser with respect to the lateral verge side of the prism (the angle of incidence of the laser radiation on the lateral verge of the prism, which borders contact with the flow of the liquid medium). To order to get degree of contrast of the light-shadow boundary \( R_c \), which allows fixing even small changes in the studying medium, it is necessary to do the following. The center of the laser beam should fall on the top face of the prism at a critical angle \( \alpha_c \):

\[
\alpha_c = \arcsin \left( \frac{n_m}{n_p} \right)
\] (1)
where \( n_p \) is the refractive index of the prism’s material.

In case of a change in the refractive index of the medium \( n_m \) upon the temperature \( T \) or the study of other media, it is possible to move the position of the semiconductor laser. The laser could be moved along of prism base in diapason 12 mm. In addition, the incidence angle of the laser radiation on the prism base could be changed. It makes possible to control a large number of liquid media at various temperatures \( T \).

Experiments have shown that it is better to use lasers with angle a plane radiation pattern (the least 22.60°). It makes possible to control the angle of the radiation input in the prism in order to adjust the position of the beam maximum for \( \alpha \) more effectively and to vary it over a wider range as compared to the case of the presence of an expanding optical system in a refractometer.

3. Research results and discussion.

Studies of different media have shown that using the design of the refractometer developed by us allows to control by the position of the light-shadow boundary not only biological solutions, medical suspensions, food products (for example, wine, juices, etc.), but also aqueous solutions of chemical fertilizers. The preparation of these solutions takes place in a continuous technological mode. This process must be controlled at different stages of production.

The figure 2 shows, as an example, the intensity of laser radiation which was recorded by a photodiode array at various concentrations of potassium \( N_k \) in the flow of aqueous solution of potassium nitrate. Potassium nitrate is successfully used as a fertilizer for growing both vegetables and fruits.

![Figure 2](image)

Figure 2. Distribution of the intensity \( I \) along the length of the photodiode array \( d \). Graphics 1, 2, 3 corresponds to \( N_k \) in%: 30; 44; 52.

Analysis of the results shows that concentration of potassium in the flowing medium can be determined from the displacement of the light-shadow boundary with the help of calibration tables and by measuring the temperature of the flowing medium.

Our studies of the flowing medium state from the displacement of changes in the light-shadow boundary of using a refractometer have shown that there are some important limitations in carrying out measurements. These changes are connected with the vignetting of the laser beam and the contrast decrease \( R_c \) of the light-shadow boundary.

The temperature of the flowing medium has a particularly significant influence on the value \( R_c \), which in some cases of a continuous production process must be changed by 20-30 °C in the increase direction and by 10-15 °C in a decrease direction. It is rather difficult to consider the correction in the shift of the light-shadow boundary from the measured value of \( T \) by a specialized sensor with the help of calibration tables during flowing medium state control.

In case of analyzing medium with impurities an error in measurement may take place. Therefore, on the basis of our studies, we proposed a technique for adjusting the position of the light-shadow
boundary in the optical scheme of the refractometer in case of changing temperature, so that the value of \( R_c \) was not less than 0.75.

It should be noted that in the design of the refractometer developed by us, are preserved functional possibilities for measuring different parameters that have other types of refractometers used.

For example, in figure 3 shows the experimental dependences of the change in the relative density of the aqueous solution in Brix units on the temperature \( T \) for various concentrations of sugar. The value of \( \Delta N = 0 \) at \( T = 293 \) K is taken as the starting point for measuring the relative concentration.

\[ \text{Figure 3. Temperature corrections for the concentration of aqueous solutions of sucrose: 1-10\%, 2 -30\%, 3 -60\%} \]

The results shown in figure 3 correspond with the results of measurements obtained with other types of refractometers [7-9].

4. Conclusion
The obtained results show, that taking into account the features of the flowing liquid medium state control by the light-shadow boundary displacement in the refractometer design allows to increase the functional possibilities if the refractometer.

In addition, it was experimentally established that it is necessary to exclude from the standard design of the refractometer the optical system the part that expands laser beam. This will provide a new technique for adjusting the optical part of the refractometer when temperature \( T \) of the liquid medium changes within the limits indicated.

5. References
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