Conference materials
UDC 535.319
DOI: https://doi.org/10.18721/JPM.183.228

Features of goniometric measurements in liquid media using triangular cuvettes

R.P. Klimenko[1]✉, V.I. Danilova[1], V.P. Klimenko[1], V.V. Davydov[2,1]

[1] Bonch-Bruevich Saint Petersburg State University of Telecommunications, St. Petersburg, Russia;

[2] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia

✉ 79213866205@yandex.ru

Abstract. A new method for measuring the refractive index of liquid media using a triangular cuvette has been developed. The features of goniometric measurements of the refractive index of liquid media using a triangular cuvette with a right angle have been determined. A cuvette design has been developed for conducting long-term studies of refractive index changes over occupied volume, which is particularly relevant for hydrocarbon mixtures. The advantages of the developed method for measuring the refractive index over industrial refractometers are highlighted. The main ones are the ability to easily measure liquid media of varying transparency and to conduct long-term measurements of volatile media. The results of studies of various media are presented and compared with measurements on industrial refractometers.

Keywords: goniometric systems, triangular cuvette, features, laser radiation, measurement accuracy, liquid medium, refractive index

Citation: Klimenko R.P., Danilova V.I., Klimenko V.P., Davydov V.V., Features of goniometric measurements in liquid media using triangular cuvettes, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 18 (3.2) (2025) 143–148. DOI: https://doi.org/10.18721/JPM.183.228

Материалы конференции
УДК 535.319
DOI: https://doi.org/10.18721/JPM.183.228

Особенности гониометрических измерений жидких сред с использованием треугольных кювет

Р.П. Клименко[1]✉, В.И. Данилова[1], В.П. Клименко[1], В.В. Давыдов[2,1]

[1] Санкт-Петербургский государственный университет телекоммуникаций им. проф. М.А. Бонч-Бруевича, Санкт-Петербург, Россия

[2] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия

✉ 79213866205@yandex.ru

Аннотация. Разработана новая методика измерения показателя преломления жидких сред с использованием треугольной кюветы. Определены особенности гониометрических измерений показателя преломления жидких сред с использованием треугольной кюветы с прямым углом. Разработана конструкция кюветы для проведения продолжительных исследований изменения показателя преломления по занимаемому объему, что особенно актуально для смесей углеводородов. Выделены преимущества разработанного метода измерения показателя преломления относительно промышленных рефрактометров. Основными из них являются возможность легко проводить измерения жидких сред различной прозрачности и проведение долговременных измерений летучих сред. Представлены результаты исследований различных сред и проведено их сравнение с измерениями на промышленных рефрактометрах.

Ключевые слова: гониометрическая система, треугольная кювета, особенности, лазерное излучение, показатель преломления, погрешность измерений, жидкие среды

Ссылка при цитировании: Клименко Р.П., Данилова В.И., Клименко В.П., Давыдов В.В., Особенности гониометрических измерений жидких сред с использованием треугольных кювет // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2025. Т. 18. № 3.2. С. 143–148. DOI: https://doi.org/10.18721/JPM.183.228

Introduction

Accurate measurements of various parameters are necessary for solving various problems in both research and practical applications [1, 2]. The methods used to perform these measurements must be universal (allowing for the investigation of a large number of media). Such methods include nuclear magnetic resonance, electron paramagnetic resonance, optical spectroscopy, and others [3–5]. These are expensive in terms of equipment and time-consuming research methods with limitations on the size of the images being studied. Not every laboratory can afford such equipment. Therefore, faster and simpler methods of studying the state of condensed media are used. One of them is related to refraction (the refractive index is measured) [6].

Currently, a large number of different methods have been developed for measuring the refractive index of a condensed medium. These include: the critical angle method, interference methods, Abbe refractometry, the differential method, and the goniometric method [7–9]. For use in laboratory conditions, goniometric measurements differ from others in their high functionality (it is possible to measure the refractive index of a medium in a liquid, solid, and, under pressure, gaseous state). Unlike interference methods, the goniometric system is less sensitive to mechanical vibrations and does not require complex adjustment.

These facts make the goniometric method of measuring the refractive index preferable when creating multifunctional experimental setups in small laboratories for studying condensed media, both liquid and solid. On the other hand, the use of goniometric measurements raises a number of difficulties related to the varying transparency of the media under study, their volatility, and the wide range of refractive index changes. This creates a number of peculiarities when performing goniometric measurements, which must be taken into account to ensure a high degree of reliability when monitoring the state of the media. To do this, it is necessary to ensure that the refractive index measurement error does not exceed 0.0001 in the measurement range from 1.32 to 1.77 [9–11]. This refractive index measurement range corresponds to 99% of all liquid media and their mixtures existing in the world. Therefore, the aim of this work is to establish these features and develop a method to ensure the measurement of the refractive index of a liquid medium with an error of 0.0001 or less in the specified range.

Materials and Methods

An analysis of various designs and systems for measuring the refractive index n [7–11] showed the potential for developing a new system based on goniometric measurements. Based on data from various laboratory experimental goniometric installations [9, 11], we developed the following design (Fig. 1).

A fundamentally new feature of the experimental setup for measuring the refractive index n of liquid media is the use of various cuvettes (triangular in shape with a right angle and a lid), as well as a new method for determining $n(\lambda_n, T_m)$ from the measured angle φ_1. This design also allows measurements of $n(\lambda_n, T_m)$ to be made at any wavelength of laser radiation. The principle of measuring n remains unchanged; all that is needed is a laser with the appropriate wavelength (preferably in a standard housing) or a tunable laser.

To measure n of liquid media on the experimental setup, we designed triangular cuvettes with a right angle and a lid. Fig. 2 shows an example of one of the triangular cuvettes we designed and its layout.

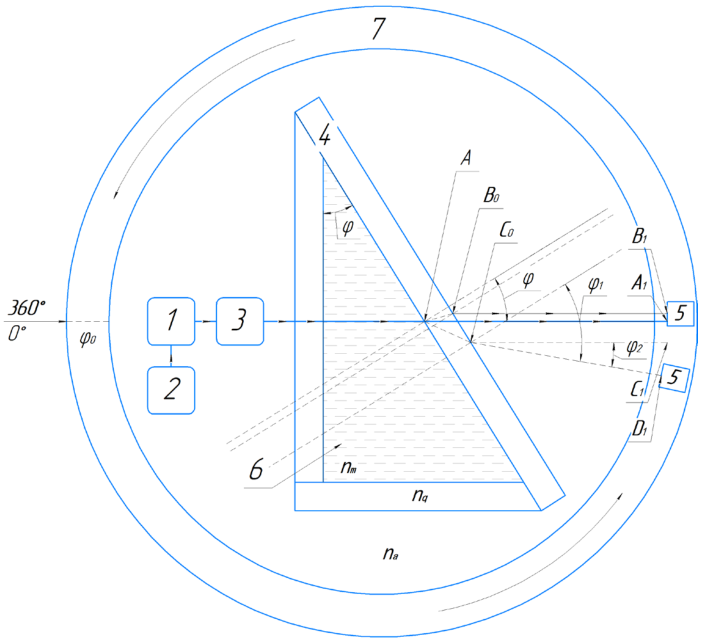

Fig. 1. Design of goniometric experimental setup for measuring the refractive index *n*: laser radiation source *1*; laser radiation power control system *2*, laser power supply unit; collimator *3*; specially shaped rectangular cuvette *4*; photodetector *5*; test medium *6*; rotary-movable device *7* for determining the angle

a) *b*)

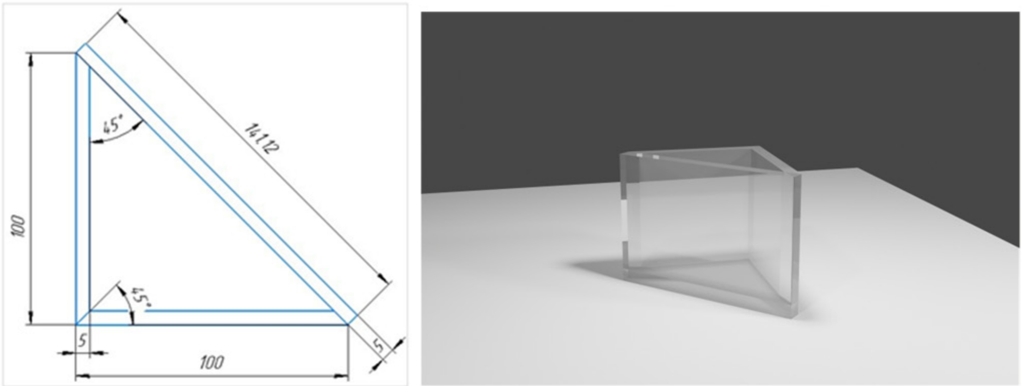

Fig. 2. Design of cuvette in the shape of an isosceles triangle (*a*), spatial model of cuvette (*b*)

The test medium 6 is placed in a triangular cuvette *4* (Fig. 1). A plane-parallel laser beam front is directed onto the wall of cuvette *4* after collimator 3. The laser radiation then passes through the medium layer and hits the edge of cuvette *4*, which is positioned at an angle to the direction of propagation of the laser radiation front. The angle φ of the triangular cuvette *4* (Fig. 1) is the angle of incidence of the laser radiation on the cuvette wall, where refraction occurs at the boundary between two media (the medium under study and quartz (the material from which the cuvette is made)). Using a movable photodetector, the position of which is set according to the maximum recorded radiation, the angle φ_1 is determined using the optical scale of the goniometer. and n is calculated. Unlike other goniometric measurement techniques, in this case only one angle φ_1 is determined. At the same time, it is possible to calibrate the instrument scale, without changing the cuvette, by angles using reference liquids, which was previously not possible with other goniometric measurements. This gives rise to a number of peculiarities in the measurement data, which we have identified.

Features of measurements using a triangular cuvette

The developed measurement method using a triangular cuvette has a number of features that significantly expand the research capabilities of goniometric measurements compared to standard optical cells [9, 11]. The main ones are as follows:

1. Laser radiation of different wavelengths from the visible range can be used for n measurements. The use of IR radiation is possible, but it will be difficult to determine the case of total internal reflection at the boundary between two media, and measurements may not be possible;
2. The use of a sealed cover, which does not create additional optical effects during measurements, allows for the study of volatile and hazardous liquid media and their mixtures;
3. The goniometer allows the cuvette to be moved horizontally and vertically. This makes it possible to study media with different degrees of transparency (by reducing the optical path of the laser beam in the medium, the attenuation of the laser radiation in terms of power is reduced). On the other hand, it is possible to study the distribution in mixtures that consist of media that do not react chemically with each other. For example, a mixture of gasoline. Study their distribution by fractions (various boundary effects between fractions) and determine the composition of the mixture and the concentrations of its components;
4. In mixtures formed by media dissolved in each other (for example, an aqueous solution of urine), it is possible to study the change in the refractive index gradient n along the height of the cuvette.

Results and discussion

To verify the accuracy of determining *n* using the new method for goniometric measurements, hydrocarbon samples were studied. Fig. 3 shows the results of the study of changes in the refractive index *n* of AI-98 and AI-100 premium gasoline with changes in temperature *T*.

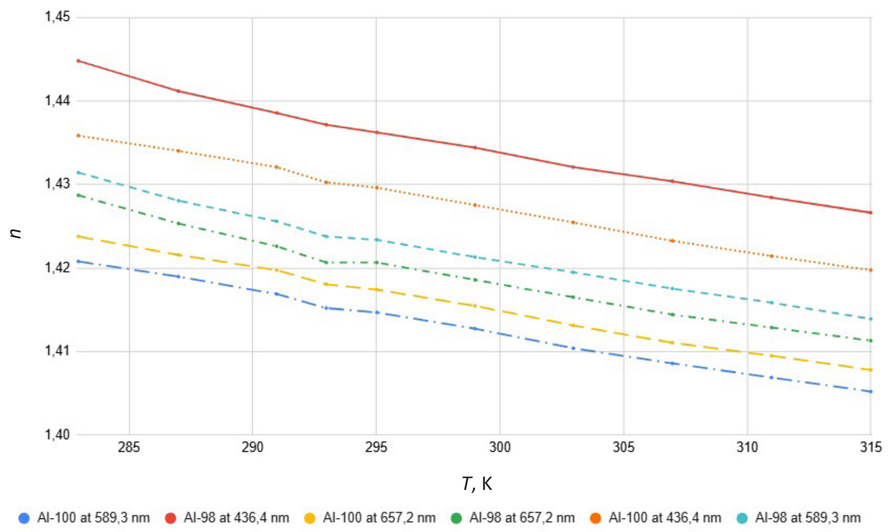

Fig. 3. Dependence of the change in refractive index *n* on the temperature *T* of AI-98 and AI-100 gasoline at three wavelengths of laser radiation

Using an Abbemat WR/MW industrial digital refractometer, the refractive indices of two gasoline samples were measured at three wavelengths at a temperature of $T = 293$ K. The values of *n* obtained using the experimental setup and the industrial refractometer coincided within the measurement error limits.

Next, to verify the effectiveness of the new measurement method and the capabilities of the experimental setup, studies were conducted on Genesis Arm 5W-30 motor oil (Lukoil company) at temperature *T*, and the results were compared with the measurements obtained using the Abbemat WR/MW industrial refractometer (Table).

Analysis of the data obtained shows that they coincide within the measurement error. This once again confirms the possibility of using the developed experimental setup design, taking into account all the features of its operation, to measure n at different wavelengths and temperatures *T*.

Table

Study of the refractive index *n* of Genesis arm 5W-30 motor oil (Lukoil company) from temperature change *T*

T, K	Laboratory goniometric system with triangular cuvette	Abbemat WR/MW Industrial Refractometer
283.2 ± 0.2	1.4704 ± 0.0001	1.47035 ± 0.00005
285.0 ± 0.2	1.4701 ± 0.0001	1.46996 ± 0.00005
287.1 ± 0.2	1.4695 ± 0.0001	1.46942 ± 0.00005
291.1 ± 0.2	1.4680 ± 0.0001	1.46797 ± 0.00005
295.0 ± 0.2	1.4663 ± 0.0001	1.46623 ± 0.00005
299.1 ± 0.2	1.4648 ± 0.0001	1.46471 ± 0.00005
303.0 ± 0.2	1.4634 ± 0.0001	1.46332 ± 0.00005
306.1 ± 0.2	1.4619 ± 0.0001	1.46179 ± 0.00005
310.2 ± 0.2	1.4604 ± 0.0001	1.46028 ± 0.00005
313.0 ± 0.2	1.4589 ± 0.0001	1.45879 ± 0.00005

Conclusion

The research conducted and the results obtained showed that the use of the developed triangular cuvettes and the new method for measuring the refractive index n, taking into account all the peculiarities of their implementation, make it possible to obtain reliable results in laboratory conditions with an error of 0.0001 for almost all existing liquid media and their mixtures.

It should be noted that the developed measurement method is universal for radiation at different wavelengths, which was confirmed by the research results. With a specific set of cuvettes and lighting close to darkness using special glasses, it is possible to conduct research at IR wavelengths, which is currently implemented in industrial refractometers for researching liquid media only for wavelengths of 1550 nm (these devices are very expensive).

REFERENCES

1. **Fisher L.M., Bobyl A.V., Johansen T.H., et al.,** Anisotropic Origin of the Bending Instability of the Flux-Antiflux Interface in Type-II Superconductors, Physical Review Letters. 92 (3) (2004) 370021–370024.

2. **Semenov A.A., Karmanenko S.F., Melkov A.A., et al.,** The propagation of magnetostatic surface waves in ferrite/superconductor structures, Technical Physics. 46 (10) (2001) 1218–1224.

3. **Eremina R., Gippius A., Gafurov M.,** Trends in Magnetism, Applied Magnetic Resonance. 54 (4-5) (2023) 435–437.

4. **Davydov V.V., Moroz A.V., Myazin N.S., et al.,** Peculiarities of Registration of the Nuclear Magnetic Resonance Spectrum of a Condensed Medium During Express Control of Its State, Optics and Spectroscopy. 128 (10) (2020) 1678–1685.

5. **Manu V.S., Olivieri C., Veglia G.,** AI-designed NMR spectroscopy RF pulses for fast acquisition at high and ultra-high magnetic fields, Nature Communications. 14 (1) (2023) 4144–4156.

6. **Karabegov M.A.,** Metrological and technical characteristics of total internal reflection refractometers, Measurement Techniques. 47 (11) (2004) 1106–1112.

7. **Contreras-Tello H., García-Valenzuela A.,** Refractive index measurement of turbid media by transmission of backscattered light near the critical angle, Applied Optics. 53 (21) (2014) 4768–4778.

8. **Chen J., Guo W., Xia M., et al.,** In situ measurement of seawater salinity with an optical refractometer based on total internal reflection method, Optics Express. 26 (20) (2018) 25510–25523.

9. **Yurin A.I., Vishnyakov G.N., Minaev V.L., Krasivskaya M.I.,** Measurement of the refractive index using an autocollimation goniometer, Scientific and Technical Journal of Information Technologies Mechanics and Optics. 23 (5) (2023) 1073–1076.

10. **Davydov V.V., Smirnov K.J.,** An Optical Method of Monitoring the State of Flowing Media with Low Transparency That Contain Large Inclusions, Measurement Techniques. 62 (6) (2019) 519–526.

11. **Yurin A.I., Vishnyakov G.N., Minaev V.L.,** Estimate of Errors in Measurements of Refractive Index by Modified Prism Methods, Measurement Techniques. 66 (3) (2023) 168–172.

THE AUTHORS

KLIMENKO Roman P.
79213866205@yandex.ru
ORCID: 0009-0007-2270-4665

KLIMENKO Vasiliy P.
klimenko.vasilij2018@yandex.ru
ORCID: 0009-0006-2892-2279

DANILOVA Valeria I.
danilova.vi@bk.ru
ORCID: 0009-0009-8013-7130

DAVYDOV Vadim V.
davydov_vadim66@mail.ru

Received 29.09.2025. Approved after reviewing 17.10.2025. Accepted 17.10.2025.