Обговорюється процес лазерної генерації звукових хвиль в сильно поглинаючих рідинах. Продемонстровано експериментальний метод, що дозволяє одночасне визначення швидкості звуку і коефіцієнта поглинання світла в рідинах. Цим методом проведені вимірювання зазначених величин в різних нафтах, а також визначено температурний коефіцієнт швидкості звуку і смолистість

Ключові слова: опто-акустичний сигнал, коефіцієнт поглинання світла, акустичні сигнал, швидкість звуку

Обсуждается процесс лазерной генерации звуковых волн в сильно поглощающих жидкостях. Продемонстрирован экспериментальный метод, позволяющий одновременное определение скорости звука и коэффициента поглощения света в жидкостях. Этим методом проведены измерения указанных величин в различных нефтях, а также определен температурный коэффициент скорости звука и смолистость

Ключевые слова: опто-акустический сигнал, коэффициент поглощения света, акустические сигнал, скорость звука

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LASER OPTOACOUSTIC METHOD FOR INVESTIGATION OF SOME PHYSICAL PARAMETERS OF OIL AND OIL PRODUCTS

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1. Introduction

For an effective selection of machines and gears for mining, transportation, processing and consumption of oil, it is necessary to know their components and parameters. The physicochemical properties of oil are extremely various; oil characteristics permanently vary even within one reservoir.

The main physical properties of oil are sound speed and absorption coefficient of light. The experimental definition of the sound speed alongside with analysis of other parameters of the medium allows calculating such relevant characteristics as compressibility and thermal capacity. The sound speed is also connected to evaporation heat, surface tension and other parameters of the medium [1, 2]. The absorption coefficient of light is the parameter, which characterizes the properties of oil with adequate accuracy [3, 4].

The existing conventional methods of sound speed measurement are composite. These methods involve the use of quartz converters, optics, a technique of photographic spectrum recording, etc. [5, 6].

For the definition of absorbency, the photoelectric calorimeter operating will be used, which is based on matching two light beams – passing through the solution with oil and through a clean solvent. The comparison of the obtained data allows defining the absorption coefficient of light. As this method also is visible is enough composite and does not give to define directly required value.

Thus, the determination of the speed of sound and the absorption coefficient in oils by a simpler method is an actual task.

2. Literature review and problem statement

The study of the physical properties of a substance in various aggregate states using the methods based on optoacoustic effects is one of the current trends in modern physics. This is due to the high sensitivity of this method in a wide spectral range, the smallness of the required amount of the analyte, as well as the possibility of performing a nondestructive analysis of the distribution of the characteristics of the medium in depth [7]. In the work [8], to study the inhomogeneities and defects in the structure of materials, ultrasonic spectroscopy and flaw detection methods are used. The methods are based on an analysis of the frequency dependences of the attenuation coefficient and the phase velocity of acoustic waves in the material under study. One of the techniques which has been widely used for the determination of low absorption of different materials is the thermal lens method [9]. When a beam of light with a Gaussian intensity profile propagates in an absorbing medium, the heat generated as a consequence of optical absorption causes the sample temperature to rise. Because the refraction index depends on the temperature, a spatial distribution of the refraction

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index of similar extension is generated in the absorbing medium.

The laser optoacoustic method of elastic modules measurement of isotropic composite materials is experimentally realized in [10]. The method is based on measurements of phase velocities of thermooptically excited pulses of longitudinal and shear acoustic waves in samples under study. Measurement of the absorption coefficient of sound absorbing materials under a synthesized diffuse acoustic field is realized in [11]. The speed of sound is also one of the main thermophysical parameters of liquids [12]. In [13], the influence of ambient temperature, electric and magnetic fields on the speed of sound in water was studied.

These studies do not consider the dependence of physical parameters on temperature. While in such liquids as oil, physical parameters are very sensitive to temperature changes.

3. The aim and objectives of the study

The aim is to develop and implement a laser optoacoustic method for simultaneous determination of the light absorption coefficient and sound velocity in oil.

To achieve the aim, let us consider the following objectives:

1. The ascertaining of the physical mechanism of ultrasound excitation under the action of a pulse of laser radiation on a liquid.
2. Development of a technique for measuring the ultrasonic velocity and the light absorption coefficient in oil.
3. The study of the temperature coefficient of the sound speed and gummosity of oils.

4. Thermo-optic sound generation

The essence of the given method is as follows. When the strongly absorbing medium is irradiated with a short laser pulse ($\tau_l \ll (\alpha c_0)^{-1}$, τ_l – pulse duration of a laser radiation, α – absorption coefficient of laser radiation in the medium, c_0 – sound speed), the heating of the medium is possible practically to consider as instantaneous (Fig. 1). Then the bulk density of the heat secured in the medium is described by the expression $\alpha\varepsilon_s \exp(-\alpha z)$, (where ε_s – density of energy, incident on the medium), and temperature variation of the medium by the expression

$$T' = \frac{\alpha\varepsilon_s}{\rho_0 c_\rho}\exp(-\alpha z).$$

During influence a laser pulse density of medium has not time essentially will change, and at the expense of an inhomogeneous temperature field forms field of mechanical stress. The expression of increment of pressure p' can be shown by the way [14]

$$p' = p - p_0 = c_0^2\rho' + c_0^2\rho_0\beta T',$$

where ρ_0 – equilibrium density of the medium, $p' = p - p_0$ – increment of density, $T' = T - T_0$ – increment of temperature and

$$\beta = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p$$

is temperature coefficient of cubic expansion of the medium, c_p – specific heat of the medium at constant pressure. In this case, it is possible to consider that $\rho' = 0$, consequently $p' = c_0^2\rho_0\beta T'$.

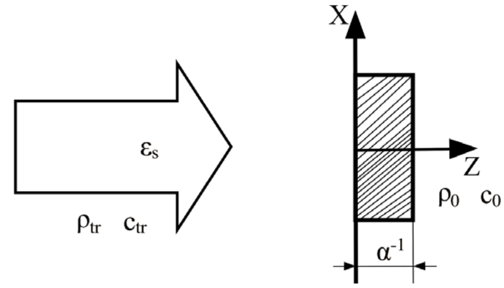

Fig. 1. Geometry of the heat release region with strong absorption of light

The field of mechanical stress, in turn, causes acoustic waves, which propagate from the heated zone. This pressure propagates equally between the wave escaping from the border $z=0$ and the wave running in the direction of the border. Outside of the area of heat release, there is only the wave propagating from the border into the depth of an absorbing medium. Its temporary profile reshapes both the direct wave, and the wave propagating to the border and reflected from it.

The profile of an acoustic wave, excited in the medium, is described by the following formula [14]

$$P' = \frac{\alpha c_0^2\beta\varepsilon_s}{2c_p}\cdot\begin{cases}\dfrac{1-N}{1+N}\cdot\exp[\alpha(z-c_0t)], & z < c_0t,\\ \exp[-\alpha(z-c_0t)], & z > c_0t,\end{cases} \quad (1)$$

where

$$N = \frac{\rho_0 c_0}{\rho_{tr}c_{tr}}$$

is the ratio of acoustic impedances absorbing and transparent mediums.

Fig. 2 presents the profiles of optoacoustic signals at various values of the parameter $\alpha c_0\tau_l$ obtained from the formula (1). As the leading edge of the pulse $(\tau = t - \frac{z}{c_0} < 0)$ is reshaped by the direct wave propagating at once from the border, its profile repeats a spacing of potential sources and for a uniform – absorbing medium (α=const) has the universal exponential form

$$p'(\tau < 0) \sim \exp(\alpha c_0\tau).$$

Reflected from the border $z=0$, the wave also has the exponential form,

$$p'(\tau < 0) \sim \exp(-\alpha c_0\tau),$$

and its relative value is determined by a reflection coefficient of the acoustic wave.

Under the form of an acoustic signal measured in depth z, it is easily possible to determine a propagation time τ of the acoustic wave from the surface up to the given point of the medium. Therefore, knowing a bed depth z, it is easy to determine the sound speed in the medium, as

$$v = \frac{z}{\tau}.$$

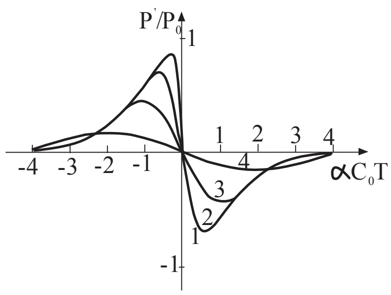

Fig. 2. Profiles of optoacoustic pulses, for free border at various values of the parameter $\alpha c_0 \tau_L$, equal 0. 1 (1); 0.3 (2); 0.7 (3) and 1.5 (4)

Considering that for homogeneous liquid, the theoretically counted form of a thermo-acoustic pulse of pressure has a simple form $p' \sim \exp(-\alpha z)$, build dependence pressure at the front of the acoustic pulse as a function of time in a semi-logarithmic scale, on a slope of a straight line the absorption coefficient of light can be determined.

5. Experimental arrangements

Our experimental arrangement is shown in Fig. 3. A periodical–pulse laser 1 operating at a wavelength 1.06 μm is used. Duration and the pulse energy are ~20 ns and ~5 mJ, accordingly. The part of radiation was routed 2 on a photodetector 3, which served for the start of a storage-type oscilloscope 6 such as C9-8. Another part of radiation was directed vertically 4 onto the liquid which is contained in a cuvette 5.

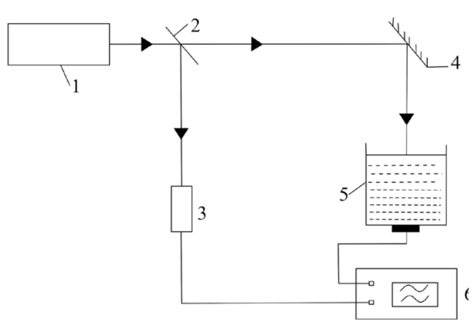

Fig. 3. The scheme of the experimental setup: 1 – periodical–pulse laser, 2 – translucent mirror, 3 – photodetector, 4 – mirror, 5 – cuvette, 6 – oscilloscope

The special cuvette shown schematically in Fig. 4 to research the temperature dependence of physical parameters of liquids is designed.

The cuvette is made of brass. On the outer surface, there are beads 1 for attaching the jacket for thermostating. Spacing intervals between an outside and internal surface of the cuvette thermostating of the jacket 15 mm are equal, which provides fast equalization of temperature. The detection of acoustic signals is carried out in real time with a fast piezoelectric detector 3, which is mounted at the bottom of the cuvette indirect contact with the liquid. The resonance frequency of an acoustic unit makes ~39 MHz. For measurement of the sound speed in a transparent liquid, where the laser radiation practically is not absorbed and generating acoustic waves in the medium do occur, on ~~a~~ the surface of liquids the thin layer 4 of an aqueous solution of copper chloride is placed. This layer, the depth of which makes no more than ~1.5 mm is in a good acoustic contact with the investigated medium 5 and plays a role of the acoustic generator. They are partitioned by a thin teflon film 6. From above of the bed of mortar of copper chloride, the glass lamina is put, which is transparent for a laser radiation. The measurements have shown that the absorption coefficient of a laser radiation in $CuCl_2$ solution makes ~50 cm^{-1}. The laser radiation is practically completely absorbed in the solution of copper chloride and produces acoustic waves, which propagate in the investigated medium.

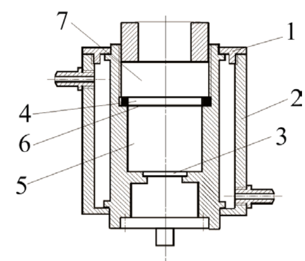

Fig. 4. A cuvette designed to investigate the temperature dependence of the speed of sound: 1 – bead, 2 – cuvette outer surface, 3 – piezoelectric detector, 4 – thin layer of aqueous solution of copper chloride, 5 – investigated medium, 6 – thin teflon film

6. Investigation results and discussion

For a check of a measuring system and experimental technique, the sound speed in water, first of all, was measured, for which at room temperature has received ~1450 $\frac{m}{s}$, that in limit of accuracies of measurement well will be agreed the known literary data [15].

The researches were conducted in oil and in different petroleum samples from various fields of Azerbaijan. The pressure in the profile of acoustic signal as a function of time in a semilogarithmic scale is presented (Fig. 5). As it is necessary to expect, the relation has a linear nature. For oil with a large absorption coefficient, the fronts of acoustic signals are more abrupt, and the slope in a semilogarithmic scale has the greater slope, accordingly.

In Table 1, the obtained data on the indicated technique of the speed of sound C_0 and absorption coefficient of light α in oil from different fields of Azerbaijan are presented. The measurement accuracy of the speed of sound did not exceed ~5 % and basically was determined by the accuracy of determining the depth of the investigated layer. And the accuracy of definition of the absorption coefficient of light was not worse than ~10 %.

Using the indicated technique, the absorption coefficient of a laser radiation for different fractions of oils was also measured. As is known, these fractions of oils are obtained in the following temperature bands; mild gasoline – 62–85 °C, heart cut distillate oil 85–180 °C, kerosene – 180–240 °C, diesel fuel – 240–350 °C, boiler oil – above 350 °C [16].

Table 1

Experimentally measured values of sound speed and absorption coefficient of light in oil from different fields

Sample No.	C0, 103 $\frac{m}{s}$	α, cm^{-1}	Fields of oil
1	1.46	1.3	Umbaku
2	1.55	2.8	Absheron
3	1.45	24.8	Salyan
4	1.47	25.2	Shirvan
5	1.6	39.3	Kura

The conducted measurements have shown that optical absorptions of radiation with a wavelength of 1.06 μ*m* in the fractions obtained up to 350 °C are practically absent.

For oil from the Oil Rocks field, α=2.7 cm^{-1} is obtained. The absorption coefficient of boiler oil obtained from this oil makes ~4 cm^{-1}, and for a resin α~14 cm^{-1}. Thus, accountable for absorptions of radiation on the given wavelength is tarry materials. When comparing the absorption coefficients of oil and resin, we found that the gummosity of the given oil is ~20 %. There is a good agreement between this value and well-known data obtained by other methods [16]. In these conventional methods, the contents of tarry materials implement allocation them from crude oil.

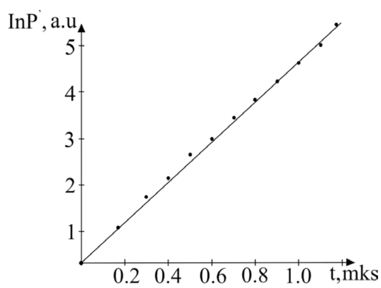

Fig. 5. The pressure in profile of acoustic signal as a function of time on a semilogarithmic scale

After that, from the weight ratios of tarry materials and taken crude oil, the contents of this fraction in oil is determined [16]. This way of definition of oil gummosity is labor-consuming enough and also is not operative.

The researches of temperature dependences have shown, that in the investigated temperature band, the absorption coefficient of radiation practically does not vary, while the speed of sound in all oils monotonically and rather essentially descends with an increase of temperature (Fig. 6).

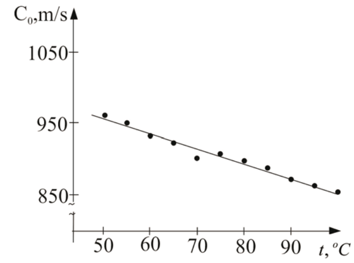

Fig. 6. Dependence of sound speed on temperature

From the experimentally derived dependences of the speed of sound on temperature, the temperature coefficient of sound velocity was determined for all oils. The temperature coefficient of sound speed of different oils varies within

$$-(2\div 8)\frac{m}{s\cdot \deg}.$$

Apparently, the decrease in the speed of sound is associated with a decrease in the modulus of bulk elasticity in oils with increasing temperature.

Thus, this method allows simultaneous and rapid determination of the absorption coefficient and sound speed, and also the study of the temperature dependence of these parameters.

7. Conclusions

1. The laser optoacoustic method of measurement of the absorption coefficient of light and sound speed of oil is proposed and experimentally realized. The proposed method is fairly simple and unlike other methods does not require the use of quartz converters, optics, the technique of photographic spectrum recording.

2. The method is based on measurements profiles of optoacoustic pulses and phase velocities of thermooptically excited pulses of longitudinal acoustic waves in samples under study.

3. The proposed method is used to measure the speed of sound and the coefficient of light absorption in various oils. The method can be applied to other liquids. In this case, the duration of the laser pulse should be sufficiently small in comparison with the time of sound travel along the depth of penetration of light.

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CALCULATION OF SOUND POWER LEVEL OF TANDEM AXIAL FAN

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Представлено результати чисельного моделювання течії в осьовому вентиляторі. Проведено тестовий розрахунок рівня звукової потужності вентилятора. Результати чисельного моделювання показали гарну збіжність. Визначено рівень звукової потужності для перших двох гармонік геометрично еквівалентного дворядного вентилятора. Результати розрахунків показали, що застосування дворядного вентилятора дає можливість зменшити загальний рівень звукової потужності на 6.8...7.4 дБ

Ключові слова: моделювання течії, рівень звукової потужності, дворядний вентилятор, тональний шум

Представлены результаты численного моделирования течения в осевом вентиляторе. Проведен тестовый расчет уровня звуковой мощности вентилятора. Результаты численного моделирования показали хорошую сходимость. Определен уровень звуковой мощности для первых двух гармоник геометрически эквивалентного вентилятора. Результаты расчетов показали, что использование двухрядного вентилятора дает возможность уменьшить общий уровень звуковой мощности на 6.8...7.4 дБ

Ключевые слова: моделирование течения, уровень звуковой мощности, двухрядный вентилятор, тональный шум

1. Introduction

The main trends in the development of aero-engine manufacturing provide for the solution of the main problem – increasing the fuel efficiency of gas turbine engines (GTE). The solution to this problem is ensured by:

– creation of new configurations of engines;
– increase in efficiency of all GTE elements;

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