Determination of the composition of liquids using spectral analysis of the electric discharge radiation

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Abstract. This article considers the reasons stimulating the research and development of a comparatively new method of analyzing the composition of liquids based on the spectral analysis of radiation of an electric discharge. Approaches to creating discharge cells for further analysis are described, including the scheme of the cell developed by the authors. To maintain the discharge has been developed a simple but rather effective electrical scheme with the use of a half-bridge driver. Emission spectra of the deionized and mains water shown in this work allow concluding that the sensitivity of the developed device is sufficient to detect even small concentrations of the substances dissolved in liquid.

1. Introduction
Nowadays the most widely used are chemical and electrochemical methods of the composition analysis of liquids, but they are relatively expensive and need a considerable time for implementation of the analysis. However there are other ways of composition definition that should be mentioned:

- photometric method, which can be used to detect nitrites, phosphates and cyanides;
- gravimetric method for analysis of fats, burnt residues and petroleum products;
- titrimetric method used for the detection of chlorides and dissolved oxygen;
- some others, such as nephelometry, infrared spectrometry and manometric methods.

There is a great interest in researching methods of spectral analysis of the composition of liquids, based on the detection of emission spectra, produced by the substances when heated by an electric discharge. Promising method is the one based on photometric registration of the emission spectra of plasma formed in the channel of an electric discharge [1, 2].

A significant problem with the present methods of the spectral analysis of the liquids composition is the initiation of the electrical discharge, which requires development of a special discharge cell in which as one or both electrodes the fluid itself is used. Such systems have rather small sizes and do not require supplementary gases, which makes them cheaper, more portable and fast compared to the other widely used emission systems.

2. Development of the discharge cell
The initiation of the discharge can be obtained using a variety of the design solutions. For such purposes the following discharge systems can be used:

- system with a liquid electrode (with electrolysis in a glow discharge);
- system with a flowing fluid;
- system with a capillary tube (with discharge in the channel).

Two of the most effective systems are the system with electrolysis in a glow discharge and a system with discharge in the channel. The peculiarity of the first system is that one of the electrodes has a low potential and the second is immersed into the liquid. Space between the electrodes is filled with air or another gas at atmospheric pressure. Initiation of the gas discharge is performed between the metal electrode and the surface of the liquid when the high voltage is applied [3].

There are no requirements to the liquid in this system. The main disadvantage of this design is that the discharge occurs in the air between two electrodes that leads to major difficulties when receiving the spectral characteristics, which in this case requires a high voltage for transmission of the energy to the substances in the water for their heating.

There is also a system design in which both electrodes are immersed into the liquid. Such system contains a capillary tube connecting two reservoirs with the analyzed liquid. Design of the developed discharge cell and the overall scheme of the research setup are shown in figure 1. This discharge cell may be submerged into the test liquid, which allows execution of the analysis in the field.

![Figure 1. Design of the discharge cell (a) and the overall scheme of the research setup (b).](image)

The reason for the use of a capillary is that it helps to increase the electric gradient in liquid with limited capacity of the power source, and the capillary contributes to this, as it increases resistance by limiting the formation of the discharge channel [4].

Discharge occurs directly in the liquid filling the capillary, which have a positive impact on the spectrum, as the glow of the electrodes (background spectrum) and also the spectral lines of the air and various substances in the air would not be received by a spectrometer.

Discharge occurring in the described above system is similar to the arc, and it is possible to allocate three stages of the process:
- voltage and current are rising to the moment of ignition of the discharge;
- ignition voltage decreases to the level of maintaining;
- current has no effect on the voltage.

This system has a serious disadvantage – a narrow capillary is polluted if it is used in insufficiently clear liquid, because the combustion substances remain on its walls, which prevents the receiving of the useful spectral data.

3. **Development of the high voltage power source**

Electric discharge in the system is achieved by applying a pulsed voltage of rectangular form using a high voltage power supply. The resulting radiance of the discharge plasma is received by an optical spectrometer through the wall of a discharge cell.
For excitation of the electric discharge in the described cell has been developed, assembled and studied a rather simple, but efficient scheme of the voltage converter based on a self-oscillating half-bridge driver IR2153 (figure 2).

![Figure 2. Scheme of the voltage converter based on a half-bridge driver IR2153.](image)

Designed circuit works from the mains with voltage 220 V and frequency 50 Hz. Voltage from the mains is rectified by VD1 and smoothed by the capacitive filters C1 and C2. Used in the experiment IR2153 chip is designed to control the field transistors that operate in a bootstrapped mode. The lower output of the C4 capacitor when voltage is applied to the chip begins to alternately switch either to the ground of the scheme or to the supply voltage line. In the moment when transistor VT2 is in the conducting state, the charge of the capacitor C4 begins to pass through the diode VD2. If VT1 is in the conducting state, the power of the upper cascade of the chip is provided due to the energy stored in C4. Use of the potentiometer R2 allows adjusting the frequency in a wide range – from 15 to 50 kHz. The voltage supplied to the transformer TR1 after its passage increases its amplitude up to 15 kV.

Configuring the discharge system is a rather complex task – it is essential to get the maximum efficiency of the excitation of spectral lines corresponding to the contained in the liquid substances, adjusting the mechanical properties of the system: size, shape and arrangement of the electrodes; and electric parameters of the high voltage power source: voltage, current and frequency of the pulses.

4. Results and discussion

In this research for the acquisition of the spectral data the ISM3600 spectrometer and ASpect2010 software were used [5–7]. Both voltage and current were controlled with an oscilloscope using a voltage divider, which reduced the values by 1000 times. Figure 3 shows the spectra obtained for deionized and mains water under the same conditions of the experiment.

![Figure 3. Spectra of the electric discharge in the deionized and mains water.](image)
In both spectra there are lines corresponding to the OH radicals (band in the range 300...320 nm) and hydrogen (656.3 nm). For mains water there are intense lines corresponding to magnesium (279.5, 285.2, 383.8, 518.4 nm), calcium (393.4, 396.8, 422.7 nm) and sodium (589.0 nm). From the spectrum (figure 3) it can be seen that even small concentrations of salts lead to the emergence of rather intense spectral lines corresponding to the dissolved elements. Spectral line 656.3 nm related to the emission of hydrogen atoms can be used for normalization of the obtained spectra.

5. Conclusions
System for analysing the composition of liquids using spectral analysis of the radiation of the discharge in liquid was developed as the result of the conducted research. This device uses a rather simple, but efficient electrical scheme of a high voltage power supply and a specially developed discharge cell. Designing was made bearing in mind the potential field usage of the device. Testing of this system using deionized and mains water showed its high sensitivity for magnesium, calcium and sodium. As for the other chemical elements results are not so promising.

For increasing the efficiency of the system a further research of the more efficient mechanical properties of the system and also electric parameters of the high voltage power source is required. It should be found an optimal scheme of the discharge cell which would allow effective obtaining of the spectral data and also be more durable and less inclined to pollution.

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