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Experimental study of temperature effects on pH and TDS in beverages

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Abstract

The paper studies the effects of temperature on such parameters as pH and TDS in various liquids, specifically in samples of water, apple juice, and carbonated beverages. Available methods and instruments for measuring the hydrogen ion concentration and total dissolved solids are considered, along with operational principles of pH and TDS meters. A study method was developed that includes repeated measurements at six different temperature levels, temperature control, instrument calibration, and rinsing of electrodes. The study provides detailed descriptions of the measurement process and precautions aimed at minimizing errors, including stabilization of readings and consideration of metrological characteristics such as accuracy, repeatability, and stability. The deviations were calculated based on multiple measurements at each temperature point. The graphs, illustrating the dependence of pH and TDS on temperature, were constructed, and the mathematical models to best represent these relations for each type of the liquid were selected. The physicochemical effects of temperature on the variation of the parameters in beverages with different chemical compositions were analysed. The results show how pH and TDS values increase or decrease at different temperature points depending on the composition of the liquid. The measurements were performed using a pH meter, TDS meter, and thermometer. The findings confirm the temperature-dependent changes in pH and TDS, emphasizing the importance of accounting for thermal conditions during storage, transportation, and quality control of beverages. These parameters may affect the taste, stability, and overall quality of beverages, making the results relevant for food industry applications and technological monitoring.

Keywords: pH meter; TDS meter; temperature; error; beverage; mathematical model.

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Introduction

In the modern world of high requirements for food safety and quality, special attention shall be paid to the control of physical and chemical parameters of beverages. This is essential in terms of assessing the product compliance with sanitary and hygienic standards, as well as ensuring the stability of taste characteristics that determine the consumer acceptability.

The pH (hydrogen index, which characterises the acidity or alkalinity of an aqueous solution) and TDS (Total Dissolved Solids, which is the total content of dissolved solids) are among these parameters. TDS characterises the total content of all salts dissolved in water, which is determined using conductometers or TDS meters. These parameters may change under the influence of temperature during storage, transportation, and even in the process of consumption.

In case of food industry, changes in pH or TDS may negatively affect not only the taste but also the safety of products. Monitoring these parameters is also crucial in daily life. For example, during storage, preparation, and consumption of a particular type of beverage under appropriate temperature conditions, pH and TDS parameters directly affect the taste and quality of the beverage.

1. Methods for measuring pH and TDS in beverages

Control of pH and TDS parameters is one aspect of metrological assurance of beverage quality. In accordance with current Ukrainian standards, potentiometric, gravimetric, conductometric, and colorimetric methods are used.

The gravimetric method for determining TDS is based on weighing the residue after water evaporation. General requirements are provided in DSTU ISO 6353-1:2012 [1] and DSTU EN 12145:2003 [2].

The potentiometric method involves the use of pH meters and ion-selective electrodes, which ensure high measurement accuracy. It is regulated by the DSTU 4869:2007 [3], DSTU ISO 1842:2013 [4], DSTU EN 1132:2005 standards [5].

The conductometric method is based on measuring the electrical conductivity of a liquid using conductometers, which allows estimating the mineralisation of a liquid and the concentration of dissolved electrolytes. General requirements are provided in DSTU 9020:2020 [6].

The colorimetric (optical) method is based on measuring the intensity of colouration of the reaction mixture. It is used to determine impurities and chemicals in liquids and food products. It is regulated, for example, by the DSTU ISO 7393-2:2004 [7] and DSTU EN 1557:2009 standards [8].

The conductometric method allows one to quickly assess the quality of water and its dissolved salt content, while the gravimetric method is a benchmark for determining TDS and provides the most accurate results, although the assessment process is longer. The potentiometric method is widely used to determine the acidity of beverages to preserve their taste and quality. The colorimetric method allows one to estimate the total acidity of a beverage and its colour.

Publications [9] and [10] study general effects of temperature on water quality, in particular on its pH, electrical conductivity, and TDS. Yet, the publications neither provide any comparative analysis for different types of liquids, nor detail the choice of measurement methods, as well as they do not consider such metrological aspect as accuracy.

2. Experimental methodology

A PH-02 type pH meter, a TDS-3 type TDS meter, and a TP101 type electronic thermometer were used for the experiments. The PH-02 device, based on the potentiometric measurement method, allows one to determine pH in solutions with an accuracy of 0.01 pH by measuring the potential difference between the measuring and reference electrodes. The TDS-3 device operates based on the conductometric method, and measures TDS by evaluating the electrical conductivity of a solution.

Then, beverages that are commonly used in daily life were selected, which have different levels of acidity and content of dissolved solids. The beverages were as follows: bottled water; tap water; mineral water; carbonated beverage; apple juice (100% natural).

It should be noted that although the temperature compensation function available in the selected devices (TDS meter and pH meter) will minimise measurement errors, caused by changes in operating temperature of the measuring elements themselves, it does not eliminate the natural (external) temperature effects on physical and chemical properties of solutions. In this study, the subject of scientific interest is the temperature effects on pH and TDS of beverages. The device temperature compensation ensures that the obtained readings correspond to the true values of pH and conductivity (which is used to determine TDS) for the current beverage temperature, and they are not distorted due to the temperature dependence of the sensor. This allows one to obtain reliable measured values for each given temperature and correctly analyse the reaction of beverages to temperature changes.

Calibration of devices

To keep measurement accuracy, it is necessary to calibrate the devices. NaCl-based solutions and distilled water are typically used to calibrate TDS meters. Calibrations with only distilled water may cause errors, so it is necessary to use calibration solutions as well. During its manufacture, the TDS meter was calibrated with a NaCl solution with a concentration of 342 ppm and additionally verified with a ready-to-use NaCl calibration solution with a concentration of 1382 ppm.

The pH meter was calibrated with three standard buffer solutions at nominal values (pH 4.01, pH 6.86, pH 9.18), which were prepared by dissolving them in distilled water.

3. Measurements and results

The samples of beverages of 100 ml volume were prepared. The temperature values (temperature points) at which pH and TDS were measured were also selected in advance, as follows: 5 °C, 15 °C, 25 °C, 35 °C, 45 °C, 50 °C. The beverages were heated to each temperature point using a water-bath, which included a flask with a thermometer for continuous measurements and temperature control. Direct multiple measurements were performed at each of the temperature points. The purpose of such measurements is to increase the reliability of measurement results by reducing the influence of random errors. After each beverage, the container and electrodes of the devices were thoroughly washed with distilled water.

Below are the interpretations of the measured parameters based on the agreement between experimental data and known physical and chemical relations.

In Fig. 1, *a*, the graph shows the dependence between the average pH value for tap water and temperature, as well as a selected third-degree mathematical model. The model may more accurately represent a non-linear dependence compared to a linear or quadratic one. It should be noted that if the coefficient of determination (R-square) is closer to 1, then this model “fits” data better and explains their variability more accurately. The obtained dependence may be because tap water may contain dissolved CO_2, which produces carbonic acid (H_2CO_3). When heated, the solubility of CO_2 decreases, which causes a decrease in the H_2CO_3 concentration, and pH increase accordingly. Tap water may also contain bicarbonate ions, which work as a buffer. When CO_2 is removed, the balance shifts, which facilitates to produce hydroxide ions, and pH increase accordingly. At high temperatures (45 °C to 50 °C), pH decreased slightly, which may be due to carbonate sedimentation ($CaCO_3$).

In Fig. 1, *b*, the graph shows the dependence between the average TDS value for tap water and temperature, as well as a selected linear mathematical model, since the obtained data have a linear dependence of the TDS increase. The obtained dependence may be because the temperature rises, the mobility of ions increases, which makes electrical conductivity of tap water increase.

It should be separately explained why two samples of apple juice, labelled by their manufacturers as "100% juice" without any additives or colourings, were selected. Both beverages are made from concentrated apple juice, which corresponds to the generally accepted technology of rectification by adding water to the initial concentration with the aim of approximating the natural composition of fruit juice.

First, a series of measurements of physical and chemical parameters of the first sample was performed. During the measurements, we noted that TDS changed together with the temperature in a way that was unusual for homogeneous fruit concentrate-based liquids.

To confirm the nature of the changes, a second sample with similar labelling was added. The results confirmed similar reaction in terms of TDS temperature dependence, but the character of the changes was manifested at a higher temperature, which may suggest differences in the concentration of dissolved substances or their ionic composition.

For the first sample, the declared characteristics are as follows: carbohydrates – 12.6 g/100 g, proteins and fats – 0 g/100 g, mineral components are potassium and sodium. The second sample is characterised by a carbohydrate content of 10.3 g/100 g and a protein content of 0.4 g/100 g.

In Fig. 1, *c*, the graph shows the dependence between the average pH value and the temperature for the first apple juice sample, as well as a selected third-degree polynomial mathematical model with non-linear dependence. The obtained dependence may be because pH of the apple juice taken determines dissociation of organic acids, in particular malic acid, which is a weak one. As the temperature increases, the dissociation constant of malic acid also increases, which stimulates the concentration of H^+ ions. At 15 °C, there is a slight increase in pH, which could be due to the balance shift in weak organic acids or a partial separation of CO_2, which temporarily lowers acidity.

In Fig. 1, *d*, the graph shows the dependence between the average TDS value and the temperature for the first apple juice sample, as well as a selected fourth-degree polynomial mathematical model with a complex non-linear dependence. The obtained dependence may be because the heating increases electrical conductivity through increased ion mobility and enhanced dissociation of organic acids. However, at the temperature point of 15 °C, there is a significant abnormal decrease in TDS, which may be associated with the aggregation of some compounds, reducing electrical conductivity. Further heating improves the substance solubility and increases TDS.

In Fig. 1, *e*, the graph shows the dependence between the average pH value and the temperature for the second apple juice sample, as well as a selected second-degree polynomial mathematical model. As in case of the first sample, the obtained dependence may be because the apple juice pH determines dissociation of organic acids (malic acid). When the temperature increases, the dissociation constant of malic acid also increases, which raises the concentration of H^+ ions and decreases pH.

In Fig. 1, *f*, the graph shows the dependence between the average TDS value and the temperature for the second apple juice sample, as well as a selected fourth-degree polynomial mathematical model. The obtained dependence may be because the heating increases electrical conductivity through greater ion mobility and enhanced dissociation of organic acids. A rapid decrease in TDS at 25 °C may be due to the aggregation of pectins or stabilisers, which reduces the concentration of free ions. Similar reaction was also observed with the first apple juice sample, but at 15 °C.

These results demonstrate that individual characteristics of composition shall be considered, even for products of an identical type.

In Fig. 1, *g* the graph shows the dependence between the average pH value and the temperature for mineral water, as well as a selected second-degree polynomial mathematical model that accounts for partial non-linearity. The obtained dependence may be because during the heating, water loses CO_2, since its solubility reduces, causing the H_2CO_3 concentration to decrease, which results in the increased pH. Hydrocarbonate ions remain in the solution, contributing to the buffer effect by increasing the pH.

In Fig. 1, *h*, the graph shows the dependence between the average TDS value and the temperature for mineral water, as well as a selected third-degree polynomial mathematical model, since it better describes the non-linear growth of TDS. The obtained dependence may be because mineral water contains a significant amount of dissolved CO_2, and also partially exists in the H_2CO_3 form. When heated, CO_2 becomes less soluble, and gas is evaporated from water. This causes a shift in the balance in a hydrocarbonate system, and the H_2CO_3 concentration decreases, while the HCO_3^- concentration relatively increases and raises TDS, since hydrocarbonate ions are part of dissolved solids.

In Fig. 1, *i*, the graph shows the dependence between the average pH value and the temperature for bottled water, as well as a selected third-degree polynomial mathematical model. The obtained dependence may be because when the dissolved CO_2 is extracted, it decreases the H^+ concentration, and also due to buffer effects of hydrocarbonates that increase alkalinity.

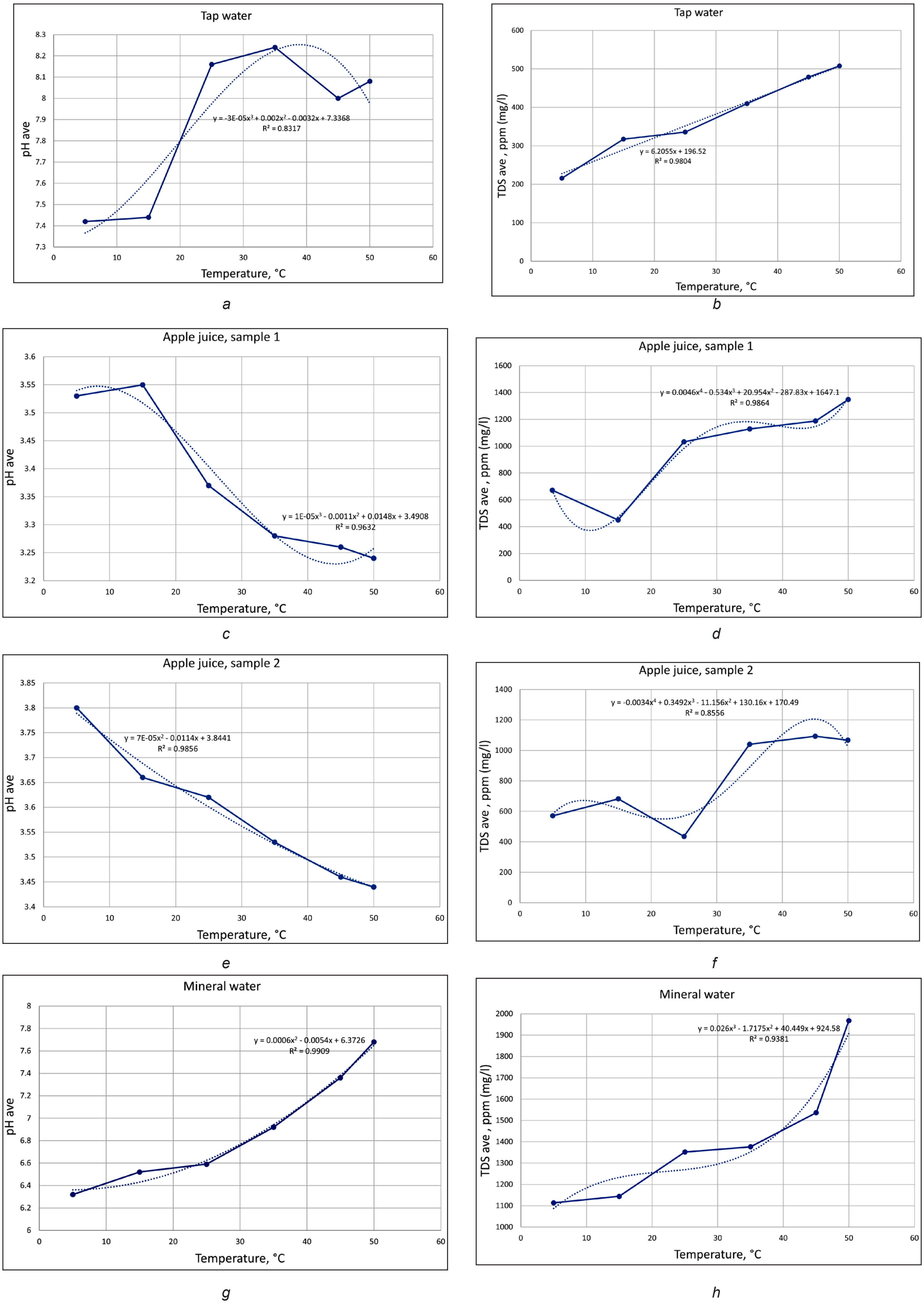
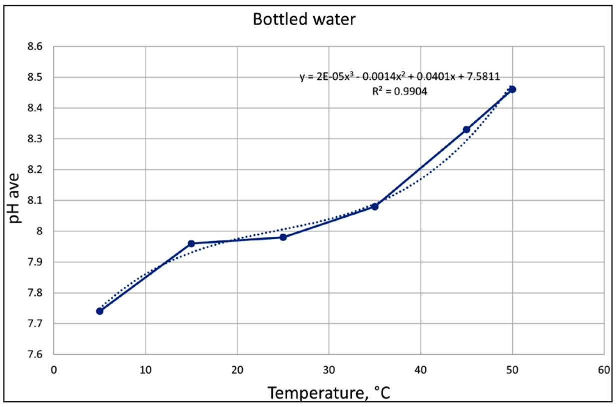


Fig. 1. Experimental dependencies



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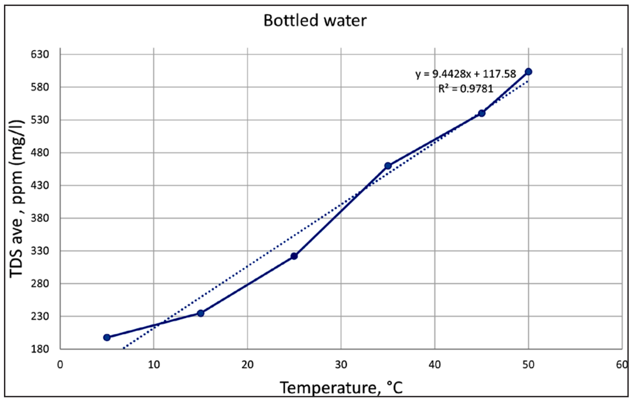

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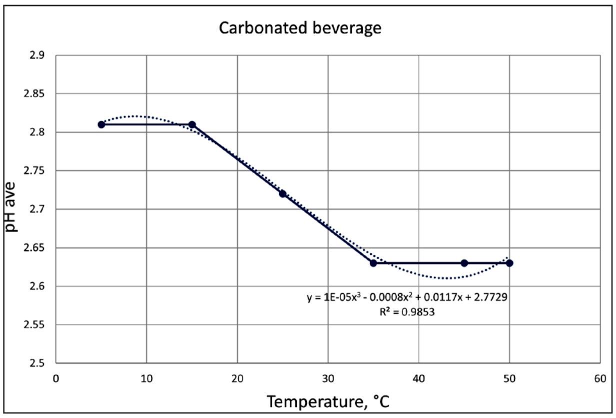

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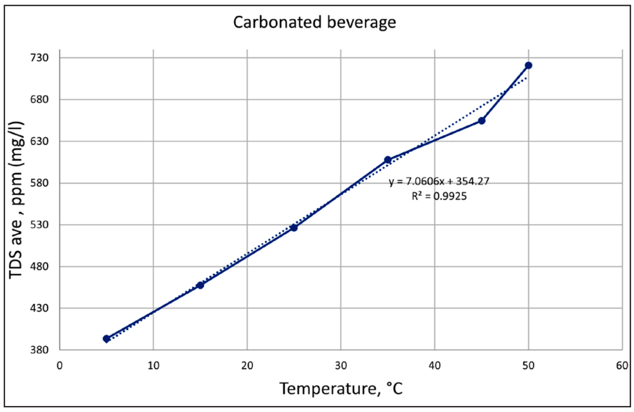

l

Fig. 1. Experimental dependencies

In Fig. 1, *j*, the graph shows the dependence between the average TDS value and the temperature for bottled water, as well as a linear mathematical model. Bottled water contained hydrocarbonates (HCO_3^-), carbonates (CO_3^{2-}), calcium ions (Ca^{2+}), and magnesium ions (Mg^{2+}). The obtained dependence may be caused by the increased ion velocity when the temperature rises, which also increases electrical conductivity and TDS values.

In Fig. 1, *k*, the graph shows the dependence between the average pH value and the temperature for a carbonated beverage, as well as a selected third-degree polynomial mathematical model. The carbonated beverage contained carbonic acid (H_2CO_3) and phosphoric acid (H_3PO_4). When temperature rises, carbonic acid dissociation increases, raising the H^+ concentration and decreasing the pH. Phosphoric acid is stronger and steadily decreases pH when the temperature rises. These two acids also have a buffer effect, which stabilises pH in some ranges (5°C ... 15°C, 35°C ... 50°C).

In Fig. 1, *l*, the graph shows the dependence between the average TDS value and the temperature for a carbonated beverage, as well as a selected linear mathematical model. When the temperature rises, the ion mobility also increases, which enhances electrical conductivity and TDS in carbonated beverages. In addition, the obtained dependence may be affected by the phosphoric acid dissociation, which also raises together with the temperature, increasing the number of ions in a beverage.

4. Errors and deviations

When measuring the beverage parameters, it is crucial to account for errors that may influence the reliability of results. Methodological recommendations [11] were used to analyse the errors.

Below is an example of calculating deviations of the pH and TDS parameters, errors, and limits for a tap water sample at a temperature equal to 5 °C, with a confidence probability $P = 0.95$.

The data for five measured pH values and the average pH value for this example are shown in Table 1.

Table 1

Table of the pH i (x_i) measured values

Temperature, °C	pH 1	pH 2	pH 3	pH 4	pH 5
5	7.50	7.42	7.42	7.42	7.34

The arithmetic mean of five pH measurement values from Table 1 was calculated using the formula:

$$\overline{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i = \frac{x_1 + x_2 + x_3 + x_4 + x_5}{5} = 7.42. \qquad (1)$$

The standard deviation of a single measurement was determined as follows:

$$\sigma = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(x_i - \overline{x}\right)^2} = 0.057. \quad (2)$$

The standard deviation of an arithmetic mean was calculated:

$$\sigma_{\overline{x}} = \frac{\sigma}{\sqrt{n}} = \frac{0.057}{\sqrt{5}} = 0.025. \quad (3)$$

As number of measurements $n < 30$ (n=5), Student's distribution to find the coefficient $t(n, P)$. So, $t(n, P) = t(5, 0.95) = 2.77$ was used [11].

The absolute measurement error was determined:

$$\Delta = \pm t\left(n, P\right) \cdot \sigma_{\overline{x}} = 2.77 \cdot 0.025 = 0.069. \quad (4)$$

The limits (lower x_l and upper x_u) of the confidence interval for a measurement result were determined:

$$x_l = \overline{x} - t\left(n, P\right) \cdot \sigma_{\overline{x}} = 7.42 - 0.069 = 7.351, \quad (5)$$

$$x_u = \overline{x} + t\left(n, P\right) \cdot \sigma_{\overline{x}} = 7.42 + 0.069 = 7.489. \quad (6)$$

A final statement of the pH measurement results, accounting for the confidence probability and calculated values, looks as follows:

$$x_t = \overline{x} \pm t\left(n, P\right) \cdot \sigma_{\overline{x}} = \overline{x} \pm \Delta = 7.42 \pm 0.07, \quad P = 0.95. \quad (7)$$

Similar calculations were performed using formulas (1)–(7) for five TDS measurement values from Table 2, temperature being equal to 5 °C, with a confidence probability $P = 0.95$. The calculated values are shown in Table 3.

Table 2

Table of the TDS i (x_i) measured values

Temperature, °C	TDS 1	TDS 2	TDS 3	TDS 4	TDS 5
5	225	225	211	211	207

Table 3

Table of the TDS calculated values

Temperature, °C	$\overline{x}$	σ	$\sigma_{\overline{x}}$	Δ	x_l	x_u
5	215.8	8.56	3.83	10.59	205.21	226.39

A final statement of the TDS measurement results, accounting for the confidence probability and calculated values, looks as follows:

$$x_t = \overline{x} \pm t\left(n, P\right) \cdot \sigma_{\overline{x}} = \overline{x} \pm \Delta = 216 \pm 11, \quad P = 0.95.$$

Similar calculations were performed for each of the selected beverage samples (using formulas (1)–(7)). It was found that the largest pH deviation was observed for the mineral water sample at 35 °C, which is explained by the reaction of dissolved gases or minerals due to temperature changes. The smallest pH deviation was observed for the carbonated beverages, and it indicates the highest stability of the samples.

The largest TDS deviations were observed for the first apple juice sample at 45 °C and for the second apple juice sample at 35 °C.

Conclusions

1. The temperature dependence of pH and TDS values in liquids with different chemical compositions has been studied, confirming that chemical parameters depend on physical and chemical composition of the environment. The graphs have been constructed, and mathematical models have been selected to describe the character of changes within the studied temperature ranges. This allows one to visualise dynamics of the processes and compare the reaction of different types to liquids during thermal exposure.

2. An experimental methodology was described, accounting for metrological characteristics of measuring instruments, which ensured the stability and repeatability of results. Calibration procedures, temperature control, and multiple measurements were used to minimise errors and increase the reliability of the obtained data.

Експериментальні дослідження впливу температури на pH та TDS у напоях

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Анотація

У статті розглянуто вплив температури на показники pH та TDS у різних рідинах, зокрема у зразках води, яблучного соку та газованого напою. Проаналізовано доступні методи та засоби вимірювання водневого показника й загального вмісту розчинених речовин, описано принципи роботи відповідних приладів, зокрема pH-метра та TDS-метра. Розроблено методику проведення дослідження, яка включає багаторазові вимірювання при шести температурних режимах, контроль температури, калібрування приладів, промивання електродів. Особливу увагу приділено мінімізації похибок, стабілізації показників, метрологічним характеристикам засобів вимірювання, включаючи точність, повторюваність та стабільність показів. Проведено розрахунок відхилень на основі багаторазових вимірювань кожної температурної точки. За результатами експерименту побудовано графіки залежності pH та TDS від температури, підібрано математичні моделі, що найточніше описують ці залежності для кожного типу рідини. Проаналізовано фізико-хімічний вплив температури на зміну параметрів у напоях з різним хімічним складом. Отримані результати демонструють, як змінюються pH та TDS залежно від температури, що підтверджує необхідність врахування температурного чинника при зберіганні, транспортуванні та контролі якості напоїв. Показники pH і TDS можуть впливати на смакові властивості продукції, її стабільність та придатність до споживання, тому результати дослідження мають практичне значення для харчової промисловості та технологічного контролю.

Ключові слова: pH-метр; TDS-метр; температура; похибка; напій; математична модель.

References

1. DSTU ISO 6353-1:2012. Chemical reagents. Reagents for chemical analysis. Part 1. General test methods. Kyiv, 2012. 30 p. (in Ukrainian).
2. DSTU EN 12145:2003. Fruit and vegetable juices. Determination of total dry matter content. Gravimetric method accounting for mass loss during drying. Kyiv, 2003. 10 p. (in Ukrainian).
3. DSTU 4869:2007. Metrology. State verification scheme for pH measuring instruments. Kyiv, 2007. 8 p. (in Ukrainian).
4. DSTU ISO 1842:2013. Fruit and vegetable products. Method for pH determination. Kyiv, 2013. 8 p. (in Ukrainian).
5. DSTU EN 1132:2005. Fruit and vegetable juices. Determination of pH. Kyiv, 2005. 10 p. (in Ukrainian).
6. DSTU 9020:2020. Metrology. Conductometers and conductometric liquid analyzers. Verification procedure. Kyiv, 2020. 20 p. (in Ukrainian).
7. DSTU ISO 7393-2:2004. Water quality. Determination of free and total chlorine. Part 2. Colorimetric method using N,N-diethyl-1,4-phenylenediamine for routine control. Kyiv, 2004. 14 p. (in Ukrainian).
8. DSTU EN 1557:2009. Surface active agents. Method for determining colorimetric characteristics of optically clear colored liquids (products) as X, Y, Z transmission color coordinates. Kyiv, 2009. 12 p. (in Ukrainian).
9. Ahmed A.T., Emad M., Bkary M.A. Impacts of temperature alteration on the drinking water quality stored in plastic bottles. *Applied Water Science*, 2021, vol. 11, article 167. doi: https://doi.org/10.1007/s13201-021-01505-2
10. Dewangan S.K., Shrivastava S.K., Kadri M.A., Saruta S. et al. Temperature effect on electrical conductivity (EC) & total dissolved solids (TDS) of water: a review. *International Journal of Research and Analytical Reviews (IJRAR)*, 2023, vol. 10, issue 2, pp. 514–519. Available at: https://www.researchgate.net/publication/371539432_TEMPERATURE_EFFECT_ON_ELECTRICAL_CONDUCTIVITYEC_TOTAL_DISSOLVED_SOLIDS_TDS_OF_WATER_A_REVIEW
11. Suslikov L.M., Studenyak I.P. Zadachi z metrologii ta metodychni rekomendatsii shchodo yikh rozvyazannya: navchalno-metodychnyi posibnyk [Problems in metrology and methodological recommendations for their solution: study guide]. Uzhhorod, 2018. 224 p. (in Ukrainian). Available at: https://dspace.uzhnu.edu.ua/jspui/handle/lib/45054