ISSN 2181-8622

Manufacturing technology problems

# Scientific and Technical Journal Namangan Institute of Engineering and Technology

INDEX COPERNICUS INTERNATIONAL

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Volume 10
Issue 3
2025

UDC 661.152.5

# STUDY OF INTERACTION OF COMPONENTS IN THE $H_3BO_3$–$KNO_3$–$H_2O$ SYSTEM

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**Abstract**: The interaction of boric acid with potassium nitrate, the main component of NPK fertilizers, was studied in 0.01 M dilute solutions using the isomolar sequence method. To determine the possible direction of the reaction in the $H_3BO_3$ – $KNO_3$ – $H_2O$ system, changes in the properties of pH, density, refractive index, viscosity and crystallization temperature of mixtures of 0.01 M boric acid and potassium nitrate solutions in different ratios were determined. The inflection points of the "composition-pH", "composition-density", "composition-viscosity" and refractive index dependences were determined. Regardless of the initial concentration of boric acid, when a small amount of potassium nitrate was added, the composition of the solution changed. To theoretically substantiate the interaction of boric acid and potassium nitrate, the physicochemical properties of their dilute aqueous solutions were studied using the isomolar sequence method. This approach involves determining the pH, density, refractive index, kinematic viscosity, and crystallization temperature of mixtures with a concentration of 0,01 M, prepared by changing the volume ratio of the components in the system [$H_3BO_3$ (0,01 M) + $KNO_3$ (0,01 M)]. Initially, 0.01 M solutions of boric acid and potassium nitrate were prepared separately. Then, increasing volumes of potassium nitrate solution were gradually added to the boric acid solution. The pH, refractive index, density, and viscosity of the resulting mixtures were measured. All experiments were carried out in a water thermostat at a constant temperature of 20 ± 0.1°C.

**Keywords:** boric acid, potassium nitrate, isomolar series, refractive index, microelements, density, viscosity, temperature, binary eutectic point.

**Introduction.** Natural soils contain many different elements, but only nine of them are considered vital microelements for plants, as they perform irreplaceable functions in their physiology. These microelements include iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), nickel (Ni), molybdenum (Mo), boron (B) and chlorine (Cl), which are necessary for the normal development of higher plants. Despite the fact that the need for these elements is small, their excess in the soil can lead to serious morphological and physiological disorders in plants [1].

Microelements are required by plants in very limited quantities, making up less than 0.1% of their dry mass. However, when accumulated in excess, some of them can exhibit toxic properties and have a negative impact on the plant organism [2]. Microelements play a key role in ensuring the vital functions of humans, animals and plants, showing their positive effects at low concentrations [3]. In addition to the specific functions of microelements, a large amount of data has been accumulated on their positive influence on the activity of enzymatic reactions and processes similar to metabolism [4].

In plant growing, boron is one of the most important microelements necessary for the normal growth of most agricultural crops [5].

The main functions of boron are related to the strength and development of the cell wall, cell division, development of fruits and seeds, transport of sugars and hormonal activity [6]. Boron deficiency in plants damages flowering and grain formation, which leads to crop losses. The sexual reproduction phase of plants is more sensitive to boron deficiency than the vegetative phase [7].

Plants such as flax, cauliflower, and sugar beet are quickly damaged and wither in boron-deficient nutrient solutions. In general, dicotyledonous plants require more boron than monocotyledonous plants [8].

One of the most effective ways to obtain agricultural products of high consumer quality is to create favorable conditions for plant nutrition, that is, to establish the correct ratio of micro- and macroelements and determine their optimal doses [9-12].

Studies have shown a positive correlation between the interaction of B and K. The combined use of these elements in fertilizers leads to an increase in seed oil content and total plant oil yield, as well as a significant acceleration of growth and an increase in nutrient availability by 40% in plants such as mung beans and beans. At the same time, while K ensures a high rate of photosynthesis, B is involved in cell division and elongation, so their interaction improves plant growth [13].

Thus, the isomolar sequence method was used to determine the quantity and norms of microelements when adding them to fertilizers.

To study the interaction of components in the $H_3BO_3$ – $KNO_3$ – $H_2O$ system, the rotation moment associated with the formation of a new phase was studied using the isomolar sequence method. Using this method, the interaction of boric acid and potassium nitrate in various ratios was theoretically substantiated. During the study, isomolar solutions of components with the same molar concentration were mixed in certain ratios using the isomolar sequence method and experimental analyses were carried out while maintaining a constant sum of the initial volumes. Based on the results obtained, the process of complex formation of boric acid and potassium nitrate was explained using graphical analysis.

Turkish scientists Bulutcu A. N. and Baloglu H. studied boron and its compounds, their properties. They investigated the solubility and parameters of binary eutectic points (temperature, density and composition) of equilibrium solid-liquid systems $H_3BO_3$-$H_2O$. The eutectic parameters were determined – temperature, density and composition of the binary system $H_3BO_3$–$H_2O$, which amounted to -0.61 ± 0.01°C, 1.0114 ± 0.0005 g/cm$^3$ and 2.37 ± 0.07 wt.%, respectively [14]. The conducted studies are aimed at obtaining complex boron fertilizers and their detailed study.

**Methods**. To theoretically substantiate the interaction of boric acid and potassium nitrate, the physicochemical properties of their dilute aqueous solutions were studied using the isomolar sequence method. This approach involves determining the pH, density, refractive index, kinematic viscosity, and crystallization temperature of mixtures with a concentration of 0,01 M, prepared by changing the volume ratio of the components in the system [$H_3BO_3$ (0,01 M) + $KNO_3$ (0,01 M)].

Initially, 0.01 M solutions of boric acid and potassium nitrate were prepared separately. Then, increasing volumes of potassium nitrate solution were gradually added to the boric acid solution. The pH, refractive index, density, and viscosity of the resulting mixtures were measured. All experiments were carried out in a water thermostat at a constant temperature of 20 ± 0.1°C.

The pH of the solutions was measured using a Mettler-Toledo FiveGoTMF2 pH meter. The relative density was determined by the pycnometric method according to GOST. The kinematic viscosity was determined using a VPJ-4 capillary viscometer with an internal capillary diameter of 1.12 mm with an accuracy of ±0.00001 $mm^2/c$.

The results of the dependence of the change in the physicochemical properties of solutions on the ratio of components in the $H_3BO_3$ and $KNO_3$ system are presented in Table 1 and Figure 1.

**Results.** Analysis of the "Composition – pH" diagram for a system containing 0.01 M solutions of boric acid and potassium nitrate showed that with an increase in the volume of $KNO_3$ solution from 3 to 30 ml, the pH value increases from 6.05 to 6.40. At the same time, with a ratio of [$H_3BO_3$ (0.01 M)] : [$KNO_3$ (0.01 M)] = 9:1, a kink is recorded on the pH change curve at a pH value of 5.40. Such a change in the pH of the medium may indicate a possible reaction with the formation of a new compound or complex formation in the solution.

**Table 1.** Changes in the physicochemical properties of solutions depending on the ratio of components in the system [$H_3BO_3$ (0,01M)+$KNO_3$ (0,01M)]

| № | Composition of components | | pH | Density, g/cm³ | Refractive index | Viscosity, mm²/c | Crystallization temprature, °C |
|---|---|---|---|---|---|---|---|
| | $H_3BO_3$, ml | $KNO_3$, ml | | | | | |
| 1 | 30 | 0 | 6,05 | 1,13160 | 1,3330 | 1,05251 | 0 |
| **2** | **27** | **3** | **5,40** | **1,12826** | **1,3331** | **1,03821** | **+0,5** |
| 3 | 24 | 6 | 5,65 | 1,12900 | 1,3330 | 1,04323 | -0,5 |
| 4 | 21 | 9 | 5,90 | 1,12911 | 1,3330 | 1,04832 | -0,7 |
| 5 | 18 | 12 | 5,98 | 1,12892 | 1,3330 | 1,05240 | -0,6 |
| 6 | 15 | 15 | 6,00 | 1,12871 | 1,3330 | 1,05023 | -0,5 |
| 7 | 12 | 18 | 6,10 | 1,12850 | 1,3331 | 1,04676 | -0,5 |
| 8 | 9 | 21 | 6,15 | 1,12843 | 1,3331 | 1,04321 | -0,4 |
| 9 | 6 | 24 | 6,20 | 1,12825 | 1,3331 | 1,03742 | -0,2 |
| 10 | 3 | 27 | 6,25 | 1,12816 | 1,3331 | 1,03321 | -0,1 |
| 11 | 0 | 30 | 6,40 | 1,12794 | 1,3331 | 1,02932 | 0 |

In the Composition – Density diagrams, with an increase in the amount of potassium nitrate and a decrease in the amount of boric acid, the density of the solutions gradually decreases from 1.13160 g/cm³ to 1.12794 g/cm³. A change in density to 1.12826 g/cm³ is also observed with a component ratio of [$H_3BO_3$ (0.01M)]:[$KNO_3$ (0.01 M)]= 9:1. This change can be explained by the interaction of potassium nitrate ions with boric acid ions, leading to the formation of a new compound.

The analysis data of the refractive index diagram show that the refractive indices of the system initially increase from 1.3330 to 1.3331, then decrease to 1.3330, and then increase again to 1.3331. When 3 ml of [$KNO_3$ (0.01 M)] solution are added, an inflection point is observed at a refractive index of 1.3331 for a component ratio of 9:1. The viscosity values of the solution of the studied [$H_3BO_3$ (0.01 M)]:[$KNO_3$ (0.01 M)] system decrease from 1.05251 to 1.02932 mm²/c. At a ratio of 9:1, an inflection point is observed at a viscosity value of 1.03821 mm²/c.

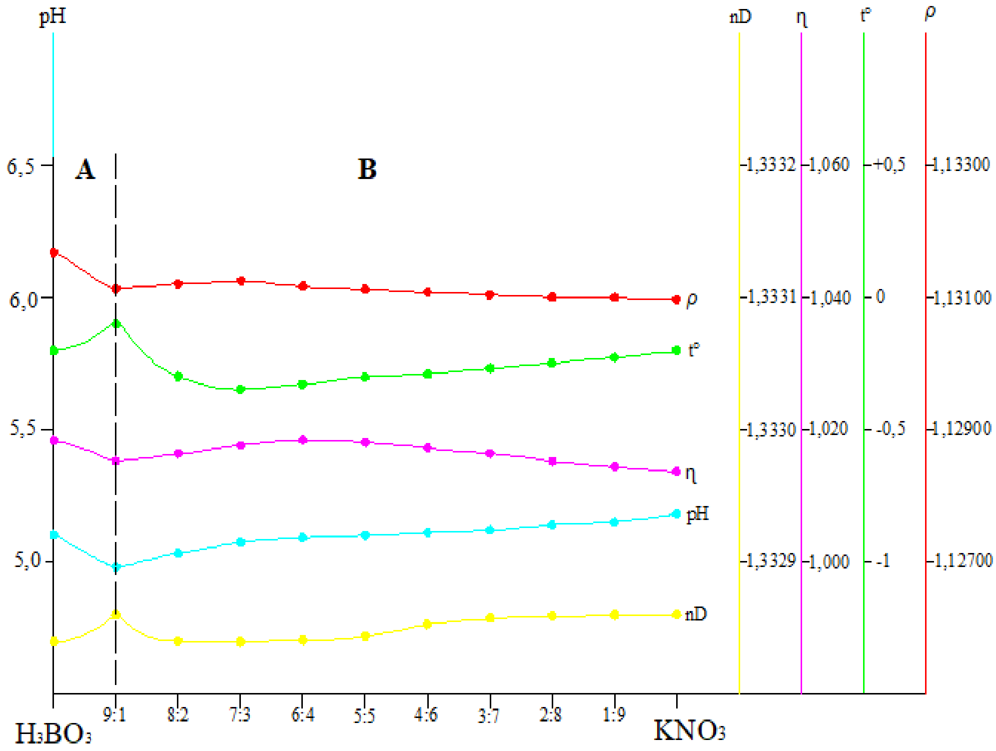


**Fig. 1.** Changes in the physicochemical properties of solutions depending on the ratio of components in the system [$H_3BO_3$ (0,01M)+$KNO_3$ (0,01M)]

In the diagram "Composition - Crystallization Temperature", with an increase in the amount of 0.01 M potassium nitrate solution from 3 ml to 30 ml, the crystallization temperature of the solutions decreases from +0.5°C to 0°C. According to the analysis of the diagram “Composition - Crystallization Temperature”, when adding 3 ml of potassium nitrate solution to the boric acid solution, the crystallization temperature increases from 0°C to +0.5°C, and at a ratio of [$H_3BO_3$ (0.01 M)]:[$KNO_3$ (0.01 M)] = 9:1, a break point is observed.

**Conclusion.** A thorough physicochemical study of the interaction of components in the $H_3BO_3$–$KNO_3$–$H_2O$ system was conducted using the isomolar method based on 0.01 M solutions of potassium nitrate and boric acid. Based on the experimental results obtained, the following main conclusions were made:

– When the ratio of components in the isomolar series changes, the physicochemical properties of solutions change significantly, such as pH, density, viscosity, refractive index and crystallization temperature;

– At a molar ratio of boric acid and potassium nitrate of 9:1, a turning point is observed for all physicochemical parameters, which indicates the possibility of the formation of a new chemical phase or compound in this ratio;

– At the same molar ratio of 9:1, a sharp decrease in pH, a minimum level of density and viscosity, significant changes in the refractive index and crystallization temperature were noted;

– The results of this study can be useful for determining the optimal ratio of boron and potassium compounds in microfertilizers, as well as for the synthesis of new complex compounds. To establish the composition of the resulting compound, a precipitate will be isolated from a concentrated solution of salts at their ratio of 9:1 and chemical and elemental analysis of the compounds will be studied.

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