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Original Article

Studying and Comparing the Ability of Iodine in Khaudak Underground Water to Sink in the form of a Compound based on Starch and Diphenylamine

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Abstract - *This paper focuses on the complex separation of iodine from groundwater in the Kkhaudak region (Surkhandarya, Republic of Uzbekistan), an area characterized by iodine-rich water and proximity to oil fields with high mineral content. Several methods were employed to isolate iodine, and the results obtained were compared. The study describes the selective transfer of iodine into compounds to facilitate its separation from groundwater, which contains a variety of minerals. Such water primari ly contains sodium chloride and is enriched with various anions and cations, including potassium, iron, calcium, magnesium, strontium, lead, copper, zinc, as well as elements like silicon, arsenic, sulfur, bromine, iodine, chlorine, phosphorus, and selenium. The formation of iodine complexes in saltwater using starch and diphenylamine was investigated, and the effectiveness of these agents was compared. Particular attention was given to the characterization of the iodine compound formed in the presence of iron (III) chloride ($FeCl_3$) and diphenylamine. Structural and compositional analyses were carried out using Infrared spectroscopy (IR), Thermogravimetric Analysis (TGA), and X-ray fluorescence (XRF). The IR spectra showed asymmetric and symmetric stretching vibrations of the amine (-NH-) group in diphenylamine at 3406 cm^{-1} and 3381 cm^{-1}, along with a characteristic secondary aromatic amine vibration at 1317 cm^{-1}. According to XRF analysis, the i odine content in the isolated complex from groundwater was approximately 6%, while the iodine separation efficiency from saltwater exceeded 90%.*

Keywords - *Diphenylamine, Starch, Khaudak water, Iron (III)-chloride, X-ray fluorescence.*

1. Introduction

Approximately 30% of the world's population suffers from iodine deficiency. This issue is particularly prevalent in countries located far from oceans and seas, as dietary iodine intake is significantly lower in such regions. Given that the majority of the world's iodine reserves are found in oceans, seas, and certain underground saline waters, the efficient extraction of iodine from these sources has become an urgent and economically significant challenge [1]. To mitigate interference during iodine analysis, an oxidation process using ultraviolet radiation was employed. This method was also applied to various samples—including pharmaceutical tablets and seaweed—to release iodine from organo-iodine compounds [2–4]. Studies have shown that the composition of the separation electrolyte strongly influences iodide migration and enrichment, mainly through specific ion-association effects [5–7].

According to some reports, iodine in water exists in various forms: approximately 85.6% as molecular iodine, 3.2% as iodide ions, 9.1% as iodate, and 2.1% as iodine chloride. Research on iodine-rich groundwater in South China revealed an average iodine concentration of 890 µg/L, with levels reaching as high as 6,350 µg/L—well above the World Health Organization's recommended limit of 5–300 µg/L. Iodide enrichment was notably observed under acidic conditions (pH = 6.6) and in a relatively low redox environment (Eh = 198.4 mV) [8, 9]. Experimental findings suggest that iodine predominantly binds with iron oxyhydroxides and organic substances in sediments.

The mobilization of iodine is believed to occur via the reductive dissolution and transformation of iron oxyhydroxides into iodide, molecular iodine, and organic iodine, processes which are enhanced by microbial activity under alkaline and reducing conditions [10–12]. Numerous sorbents have been synthesized for iodine separation. These include polymeric sorbents prepared from epichlorohydrin and diethyl-dithiophosphate, and materials that utilize urea, formaldehyde, and 1-naphthylamine with Cu(II) ions under weakly acidic conditions [13]. Additionally, sorbents based on metal-organic complexes have been developed. Notable

examples include the Zn(II) complex of 2,4-dichlorophenoxyacetic acid (2,4-D) and ethylenediamine, bis (8 - hydroxyquinoline) naphthalene - 1, 5 - disulfonate tetrahydrate, as well as cadmium complexes with naphthalene - 1, 5 - disulfonate and o-phenylenediamine. Simultaneously, synthesising superabsorbent hydrogels based on starch copolymers with mineral powders and using covalently immobilized polyampholytes derived from amino acids for metal sorption are gaining attention for their potential in iodine extraction applications. Khaudak groundwater (Uzbekistan, Surkhandarya region) has a very high mineral content, equal to 250-270 gr/l. The iodine content of this water is 21.32 mg/l [14]. The main aim of the research. The iodine-containing compounds in groundwater brine are first oxidized and then separated by lowering the pH to form a precipitate in a complex with diphenylamine and starch. A mutual comparison of the productivity indicators of complex sediments obtained based on starch and diphenylamine. The following tasks were set for the implementation of this goal:

1. The choice of conditions for forming a complex compound of starch and diphenylamine with high selectivity for more iodine separation than for other elements from water with different ions.
2. Study and cross-comparison of the composition and some properties of iodine complexes isolated based on chemical sorption.

2. Materials and Methods

2.1. R Analysis

The structure of the complex compound was analyzed using a SHIMADZU (Japan) IR spectrometer in the 4000–600 cm^{-1} range with a resolution of 4 cm^{-1}, using the powder method.

2.2. X-Ray Fluorescence (XRF) Analysis

Elemental analysis was performed using a SHIMADZU EDX-8100P XRF spectrometer. The device operates with an Rh-anode X-ray tube at 4–50 kV, detecting elements from carbon to uranium. It provides high sensitivity with a concentration range from ppm to 100%.

2.3. TGA and DTA Analysis

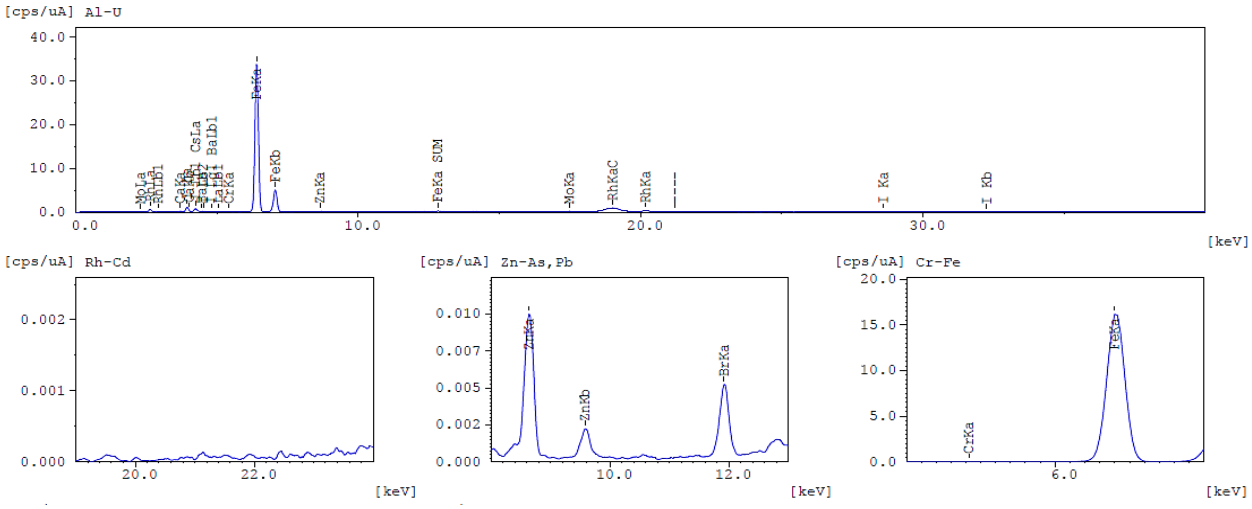
Thermal analysis was carried out using a SHIMADZU simultaneous thermal analyzer. The system supports TGA, DTA, and DSC methods and was used to study the sample's thermal stability and decomposition behavior.

3. General Procedure

The iodine-containing compounds in groundwater brine were separated by first oxidizing them using iron (III) chloride crystal hydrate, and then precipitating them as a complex with starch and diphenylamine. The composition of the resulting complex sediments was analyzed using an X-ray fluorescent analyzer. The process was carried out several times by changing the amount of reagents.

4. Detection Method

The composition of the resulting complex deposit was analyzed using a SHIMADZU (Japan) infrared spectrometer. The analysis was performed using the powder method in the 4000–600 cm^{-1} range, with a resolution of 4 cm^{-1}. Quantitative analysis of the resulting sediments was carried out using the SHIMADZU EDX-8100P X-ray fluorescence spectrometer. This instrument is capable of detecting elements from carbon to uranium, offering high sensitivity due to the use of silicon drift detectors in its design. It is widely used in various fields of science and industry. It allows for fast measurements without requiring extensive sample preparation. The X-ray tube uses a Rh-anode and operates at 4–50 kV, with a concentration detection range from ppm to 100%. The thermal properties of the compound were examined using a Thermo-Gravimetric Analyzer (TGA) from SHIMADZU. This convenient, reliable, and efficient thermal analysis platform supports simultaneous TGA-DTA and TGA-DSC measurements. It is used for component identification, measurement of optical properties, and various research purposes.



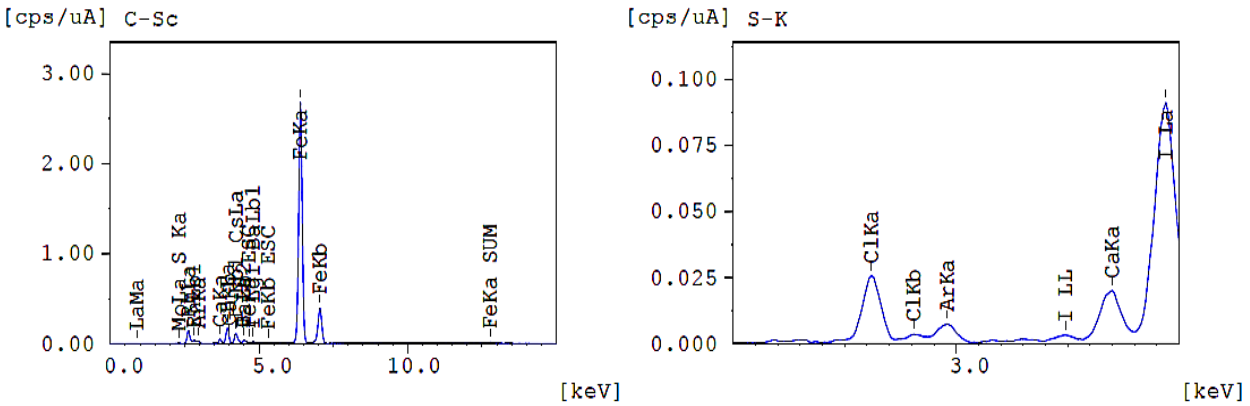


Fig. 1 Spectrum of iodine concentrate obtained based on starch in the X-ray fluorescence analyzer

4.1. Separation and Analysis of Iodine in KKhaudak Underground Water as a Complex Compound Using Starch

500 mL of KKhaudak groundwater was taken, and 2 mL of 30% $FeCl_3$ solution was added and mixed. The solution was allowed to react for 10 minutes to oxidize the iodine compounds.

Then, 10 mL of 5% starch paste was added and shaken for 1 minute. A starch–iodine complex was formed and left to precipitate for 24 hours at 20–25 °C. After filtration, 0.42 g of black sediment was obtained. The elemental composition of the precipitate was analyzed using the X-ray fluorescence spectrometer (see Figure 1 and Table 1).

Table 1. Quantitative result of iodine concentrate obtained based on starch in the X-ray fluorescence analyzer

Analyte	Result	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
Fe	7.382 %	[0.024]	Quan-FP	FeKa	116.1055
Cl	2.280 %	[0.079]	Quan-FP	ClKa	0.2573
I	0.866 %	[0.035]	Quan-FP	I Ka	3.0190
Cs	0.552 %	[0.018]	Quan-FP	CsLa	2.0804
Ca	0.222 %	[0.009]	Quan-FP	CaKa	0.4087
S	0.153 %	[0.012]	Quan-FP	S Ka	0.0928
Zn	0.042 %	[0.002]	Quan-FP	ZnKa	0.0908
Ba	0.039 %	[0.027]	Quan-FP	BaLa	0.1752
Cr	0.020 %	[0.002]	Quan-FP	CrKa	0.1787
Mo	0.008 %	[0.002]	Quan-FP	MoKa	0.7904
Br	0.005 %	[0.000]	Quan-FP	BrKa	0.0443
Organic matter	88.429 %	[------]	Balance	--------	--------

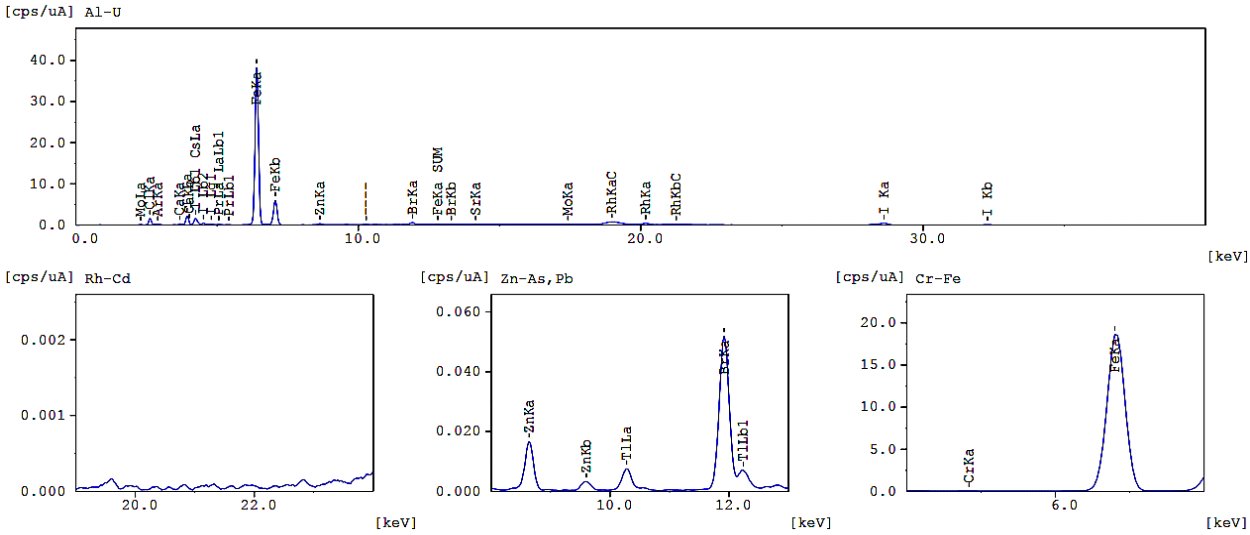


Fig. 2 Spectrum of iodine concentrate obtained based on DPA in X-ray fluorescent analyzer

5. Separation and Analysis of Iodine in Khaudak Groundwater as a Complex Compound by Diphenylamine (DPA)

1 L of KKhaudak groundwater was taken, and 5 mL of a 30% $FeCl_3$ solution was added. The solution was left to stand for 10 minutes, during which the color changed from colorless to yellowish. Then, 10 mL of a 10% diphenylamine (DPA) solution in ethyl alcohol was added and mixed for 1 minute. The mixture was stored at room temperature (20–25 °C) for 36 hours and then filtered. As a result, 0.245 g of dark green sediment was obtained.

Based on the luminescence phenomenon observed in the isolated substance, the elemental and chemical composition was determined by analyzing the changes in electron energies during excitation (see Figure 2 and Table 2).

Table 2. Quantitative result of iodine concentration obtained based on DPA, in X-ray fluorescent analyzer

Analyte	Result	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
Fe	10.041 %	[0.033]	Quan-FP	Fe Ka	133.2243
Cl	4.679 %	[0.097]	Quan-FP	Cl Ka	0.7217
I	3.883 %	[0.104]	Quan-FP	I Ka	9.2306
Cs	1.252 %	[0.031]	Quan-FP	CsLa	5.1139
Ca	0.227 %	[0.009]	Quan-FP	CaKa	0.4717
S	0.192 %	[0.013]	Quan-FP	S Ka	0.1653
Br	0.069 %	[0.002]	Quan-FP	BrKa	0.4974
Zn	0.069 %	[0.003]	Quan-FP	ZnKa	0.1373
Pr	0.060 %	[0.019]	Quan-FP	PrLa	0.2941
Tl	0.032 %	[0.002]	Quan-FP	TlLa	0.0706
Cr	0.019 %	[0.003]	Quan-FP	CrKa	0.1337
Sr	0.017 %	[0.002]	Quan-FP	SrKa	1.3192
Mo	0.016 %	[0.002]	Quan-FP	MoKa	1.2546
Diphenylamine	79.446 %	[------]	Balance	--------	--------

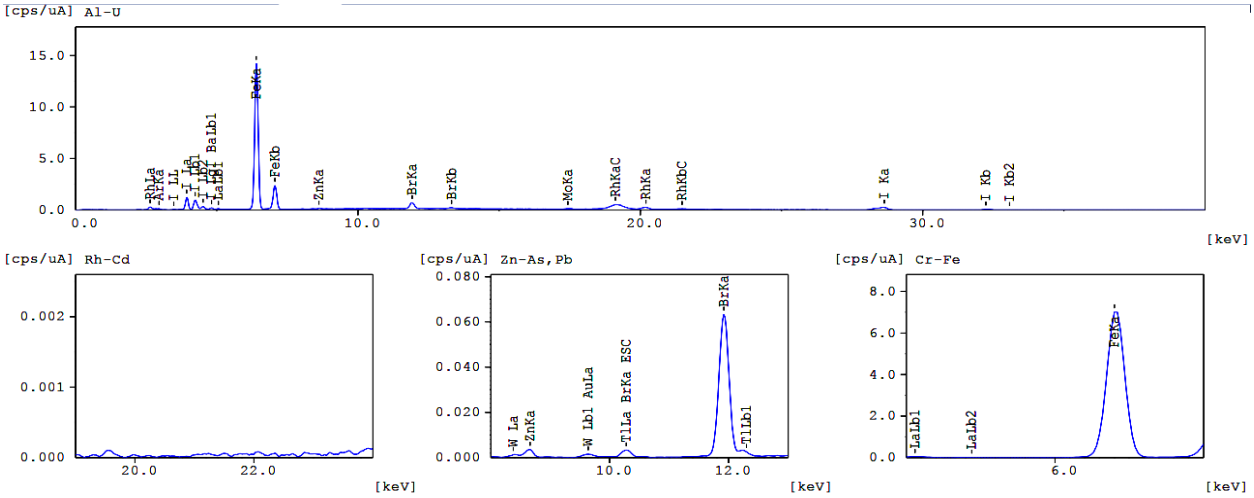


Fig. 3 Spectrum of iodine concentrate obtained based on DPA in X-ray fluorescent analyzer

Table 3. Quantitative result of iodine concentration obtained based on DPA, in X-ray

Analyte	Result	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
I	3.358 %	[0.085]	Quan-FP	I Ka	5.2180
Fe	3.225 %	[0.012]	Quan-FP	FeKa	50.4493
Cl	0.779 %	[0.040]	Quan-FP	ClKa	0.1106
Br	0.077 %	[0.002]	Quan-FP	BrKa	0.6251
Tl	0.015 %	[0.001]	Quan-FP	TlLa	0.0406
Zn	0.010 %	[0.001]	Quan-FP	ZnKa	0.0276
Mo	0.009 %	[0.001]	Quan-FP	MoKa	0.5720
Au	0.004 %	[0.000]	Quan-FP	AuLa	0.0083
Diphenylamine	92.523 %	[------]	Balance	--------	--------

2 ml of a 30 % solution of $FeCl_3$ was added to 0.5 ml of KKhaudak groundwater. The solution was waited for 10 minutes until it became yellowish (oxidized) from a colorless state, and 4 ml of a 1-molar solution of diphenylamine (DPA) in ethyl alcohol was added to it, and mixed for 1 minute, stored for chemical sorption at 20-25 °C (room temperature) for 72 hours, then filtered. The composition of the separated substance was determined based on X-ray fluorescent analysis (Figure 3 and Table 3). 0.5 L was taken from the KKhaudak groundwater, and 2 ml of a 30 % solution of $FeCl_3$ was added to it. The solution was left for 10 minutes from the colorless state until it became yellowish (until oxidized), and 7.5 ml of a 1-molar solution of DPA in ethyl alcohol was added to it, and mixed for 1 minute, kept at 20-25 °C (room temperature) for 60 hours, for chemical sorption and then filtered.

As a result, 0.553 g of green sediment was obtained. The amount of substances contained in the separated sediment was determined based on X-ray fluorescent analysis (Figure 4 and Table 4).

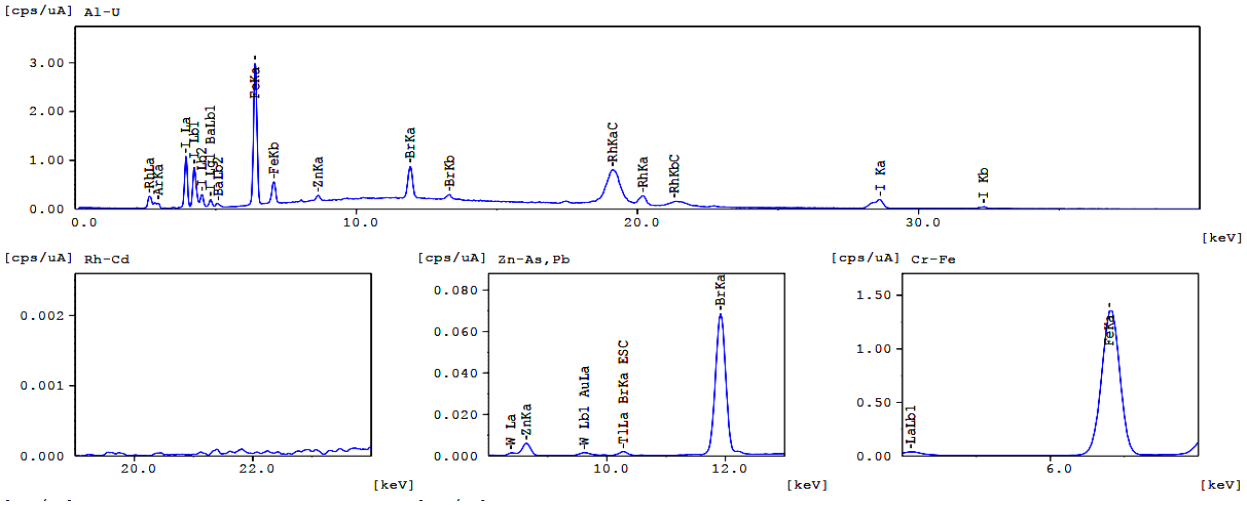


Fig. 4 Spectrum of iodine concentrate in X-ray fluorescent analyzer

Table 4. Quantitative result of iodine concentrate in X-ray fluorescent analyzer

Analyte	Result	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
I	1.709 %	[0.045]	Quan-FP	I Ka	3.8284
Cl	1.328 %	[0.074]	Quan-FP	ClKa	0.0966
Fe	0.803 %	[0.007]	Quan-FP	FeKa	9.7264
Br	0.070 %	[0.001]	Quan-FP	BrKa	0.6822
Zn	0.018 %	[0.001]	Quan-FP	ZnKa	0.0512
Tl	0.005	[0.001]	Quan-FP	TlLa	0.0147
Au	0.002 %	[0.001]	Quan-FP	AuLa	0.0051
Diphenylamine	96.065 %	[------]	Balance	--------	--------

The Iron-diphenylamine-iodine complex was obtained using a potassium iodide (KI) solution. To do this, 250 ml of a 0.2 % solution of KI was prepared, and then 5 ml of a 0.1 molar solution of $FeCl_3$ was added to it. For 10 minutes, the color of the solution has become reddish-yellow (oxidized iodine color). 4 ml of a 1-mole solution of diphenylamine (GOST-5825-70) in ethyl alcohol was added. The solution was shaken for 10 minutes and kept at room temperature for 10 days until a precipitate was formed.

The resulting iron-diphenylamine-iodine complex was filtered and dried at room temperature (20-25°C) (Figure 7). 1.65 ml was taken from the KKhaudak groundwater, and 8 ml of a 30% solution of FeCl3 was added to it and mixed. 10 minutes were waited until the solution was oxidized, and 6 ml of the solution of DPA in 10% benzyl alcohol was added to it and mixed. It was then kept at room temperature for 84 hours and then filtered.

The result was a dark green 0.56 g precipitate and a substance consisting of iodine dissolved in benzyl alcohol, the bulk in benzyl alcohol, DPA in the upper part of the solution, and benzyl alcohol in the extraction state (Figure 8, Table 5).

6. Results and Discussion Obtaining an Iodine Complex Compound based on Diphenylamine

Potassium iodide contained in KKhaudak brine with high mineral content was oxidized using $FeCl_3$ salt and characterized based on the following reaction:

$$2FeCl_3 + 2KI \xrightarrow{15\text{-}20\ ^0C} 2FeCl_2 + 2KCl + I_2$$

Since the reaction is carried out at a relatively low temperature, an additional reaction also results in Iron (III) iodide:

$$FeCl_3 + 3KI \xrightarrow{15\text{-}20\ ^0C} FeI_3 + 3KCl$$

Iron(III) iodide is a relatively unstable compound. To prevent its decomposition, a sufficient amount of diphenylamine dissolved in benzyl alcohol is added to the solution. This helps avoid exposure to light and ultraviolet radiation, leading to an iron(III)-diphenylamine-iodine complex.

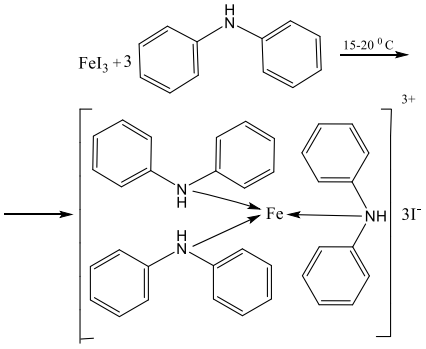


Fig. 5 Reaction for $FeCl_3$ & KI

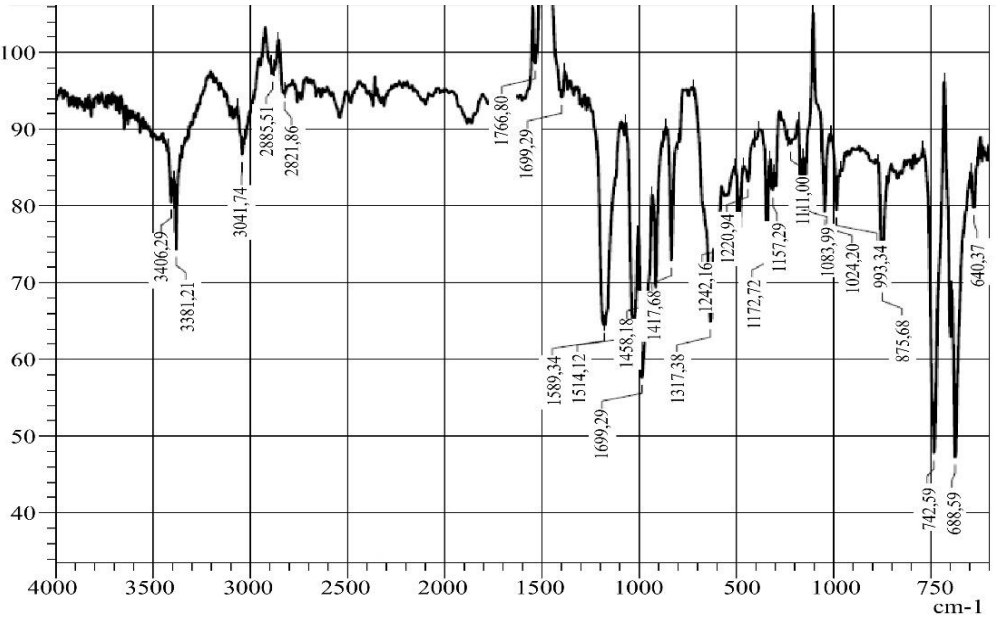


Fig. 6 The infrared spectrum of the complex precipitate obtained from solutions of KI and diphenylamine

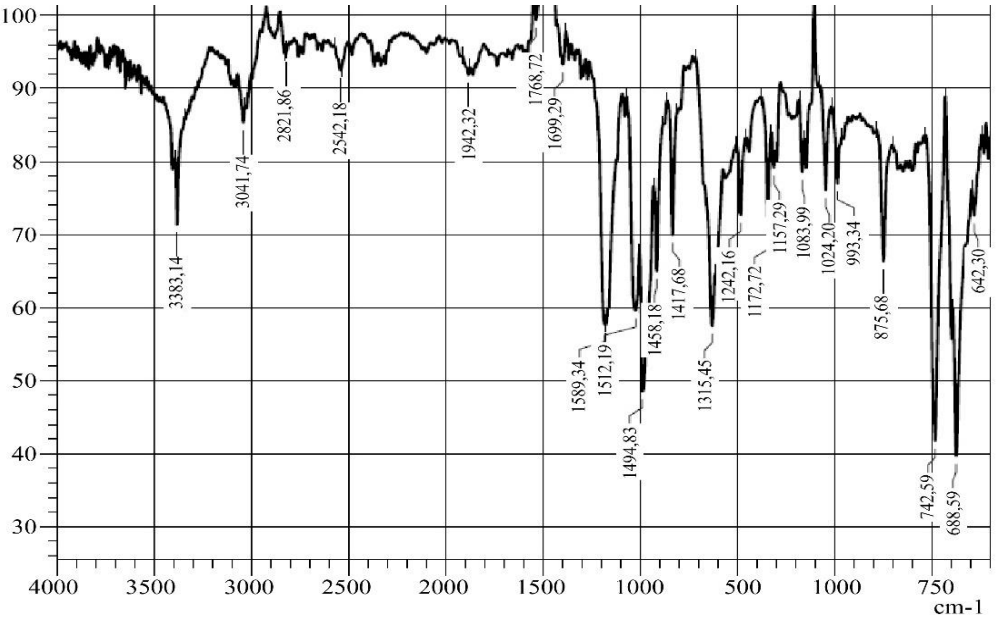


Fig. 7 The infrared spectrum of complex sediment obtained based on solutions of Khaudak groundwater and diphenylamine

7. Expression of Structure

The composition of the complex sediment obtained in the e-laboratory work was considered in the SHIMADZU infrared spectrometer (Figure 6). Asymmetric and symmetric valence vibrations of the –NH group in diphenylamine were observed at 3406 cm^{-1} and 3381 cm^{-1}, respectively. Valence vibrations of the –NH group in secondary aromatic amines were observed at 1317 cm^{-1}. In the regions of 2542 cm^{-1}, 1492 cm^{-1}, and 1458 cm^{-1}, irregular vibrational modes corresponding to the functional groups of the benzene ring were observed.

The valence vibration frequencies of the C–H bonds in the aromatic ring were detected at 3041 cm^{-1}, 1589 cm^{-1}, and 1514 cm^{-1}. Absorption bands corresponding to iron–iodine bonds in the diphenylamine–iron–iodine complex were found in the range of 500–400 cm^{-1}; however, no significant peaks in this range were observed in the recorded spectrum. The composition of the complex precipitate obtained in the f-experiment was analyzed using a SHIMADZU infrared spectrometer and compared with that from the e-experiment (Figure 7).

The absorption spectra in this figure are similar to the values presented in Figure 6, and the following vibrational frequencies were observed: asymmetric and symmetric valence vibrations of the –NH group appeared at 3404 cm^{-1} and 3383 cm^{-1}, respectively; the –NH– group vibration was observed at 1315 cm^{-1}; and characteristic bands of the benzene ring were recorded at 2542 cm^{-1}, 1495 cm^{-1}, and 1458 cm^{-1}. The infrared spectra of the complex compound based on Khaudak ground brine and diphenylamine were found to be similar to those of the iodine complex formed from KI and diphenylamine.

8. Quantitative Composition

Even when the amount of substances contained in the separated precipitate is considered based on the analysis of the X-ray fluorescent analyzer, we can see that the compound contains 5.841 % iodine (Figure 8, Table 5).

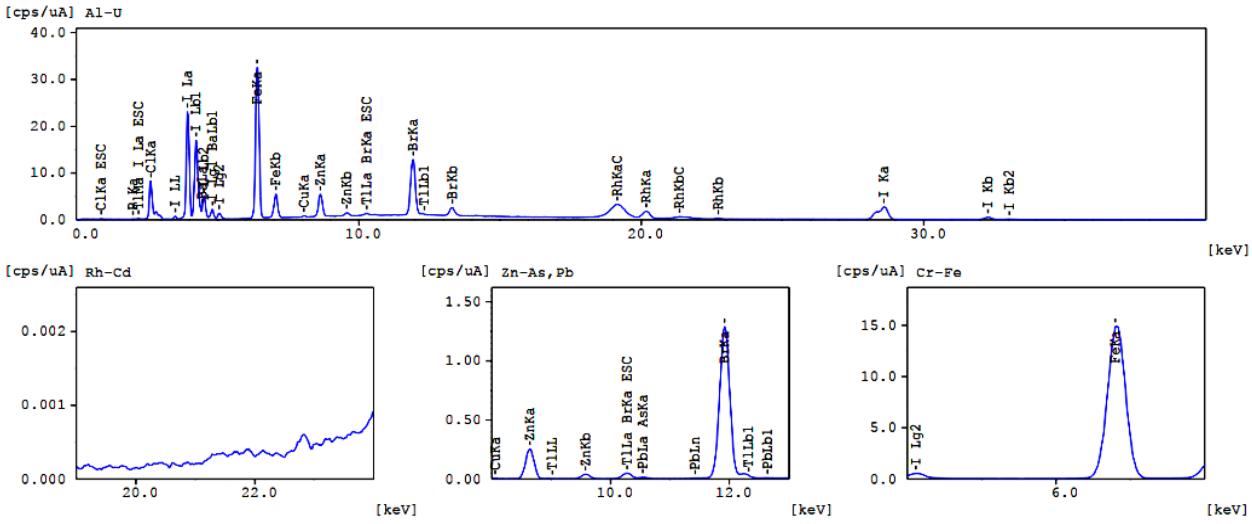


Fig. 8 Spectrum of iodine precipitate in X-ray fluorescence analyzer

Table 5. Quantitative composition of iodine precipitate in X-ray fluorescence analyzer

Analyte	Result	[3-igma]	Proc.-Calc.	Line	Int.(cps/uA)
I	5.841 %	[0.079]	Quan-FP	I Ka	59.6894
Cl	4.660 %	[0.046]	Quan-FP	ClKa	3.5443
Fe	1.688 %	[0.008]	Quan-FP	FeKa	106.5727
Ba	0.306 %	[0.040]	Quan-FP	BaLa	6.8478
Br	0.278 %	[0.001]	Quan-FP	BrKa	12.7754
Al	0.265 %	[0.080]	Quan-FP	AlKa	0.0444
P	0.174 %	[0.017]	Quan-FP	P Ka	0.2681
Zn	0.149 %	[0.002]	Quan-FP	ZnKa	2.1785
Tl	0.024 %	[0.001]	Quan-FP	TlLa	0.3527
Cu	0.007 %	[0.001]	Quan-FP	CuKa	1.5840
Pb	0.002 %	[0.000]	Quan-FP	PbLb1	0.0353
Diphenylamine	86.607 %	[------]	Balance	--------	--------

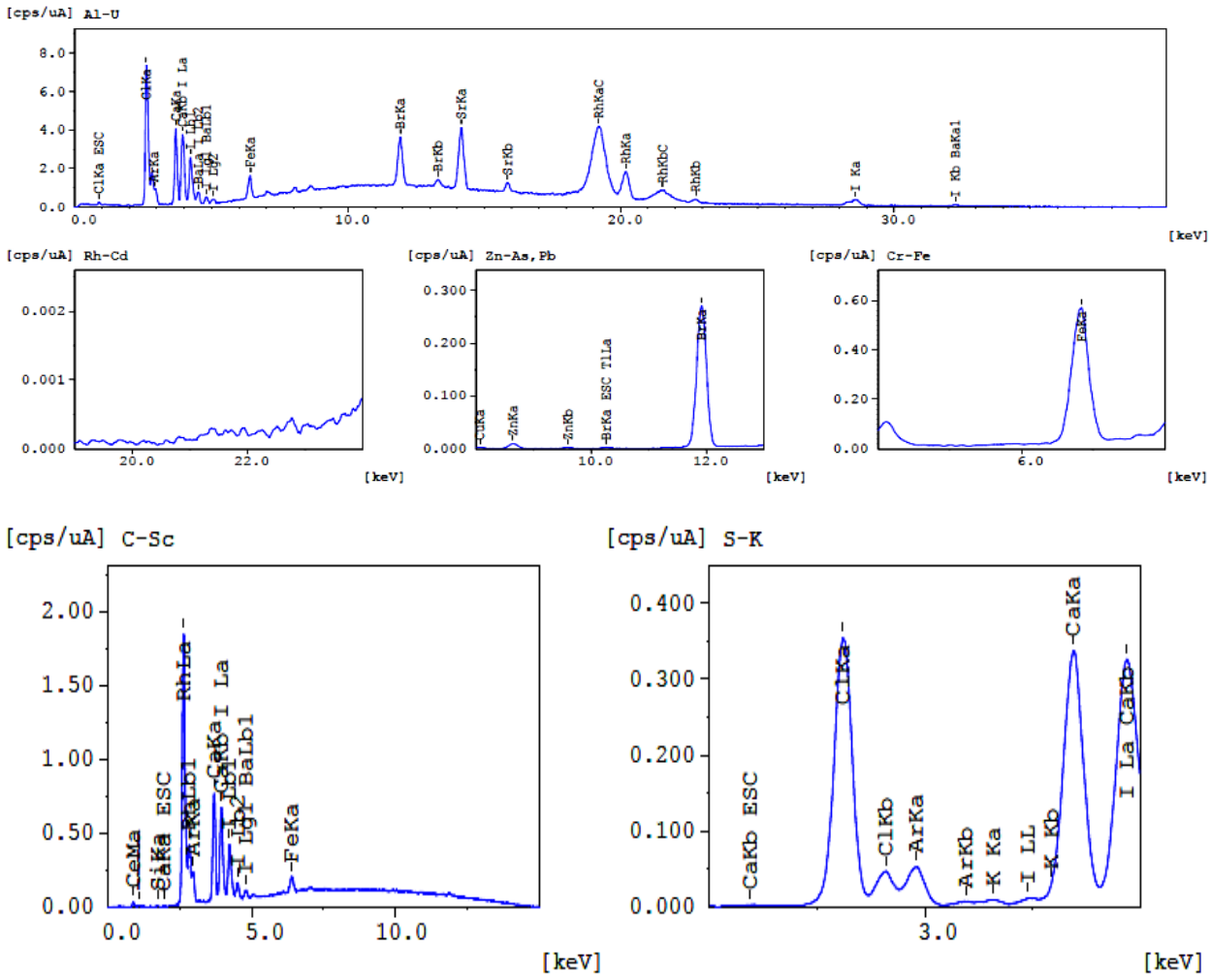


Fig. 9 Spectrum in X-ray fluorescent analyzer of the part of the reagent added to precipitate iodine that is not involved in sediment formation

Table 6. Quantitative results in the X-ray fluorescent analyzer of the part of the reagent added to precipitate iodine that is not involved in sediment formation

Analyte	Result	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
Cl	3.995 %	[0.042]	Quan-FP	ClKa	3.5478
Ca	0.638 %	[0.010]	Quan-FP	CaKa	8.1812
I	0.605 %	[0.024]	Quan-FP	I Ka	6.3371
Si	0.104 %	[0.022]	Quan-FP	SiKa	0.0700
Sr	0.057 %	[0.001]	Quan-FP	SrKa	35.1879
Ba	0.047 %	[0.013]	Quan-FP	BaLa	1.3498
Br	0.039 %	[0.000]	Quan-FP	BrKa	2.6968
Fe	0.028 %	[0.001]	Quan-FP	FeKa	3.7644
K	0.012 %	[0.003]	Quan-FP	K Ka	0.0336
Zn	0.003 %	[0.000]	Quan-FP	ZnKa	0.0777
Tl	0.000 %	[0.000]	Quan-FP	TlLa	0.0037
Organic substances	94.473 %	[------]	Balance	--------	--------

According to the experiment, 1.25g of black liquid, immiscible with salt water, was obtained in the upper part of the solution. Its main part is benzyl alcohol; the rest consists of DPA and iodine dissolved in benzyl alcohol (Figure 9 and Table 6).

This liquid can be used again to isolate iodine. After the iodine contained in the KKhaudak water was isolated based on diphenylamine, the remaining saline content was analyzed in an X-ray fluorescent analyzer (Figure 10, and Table 7).

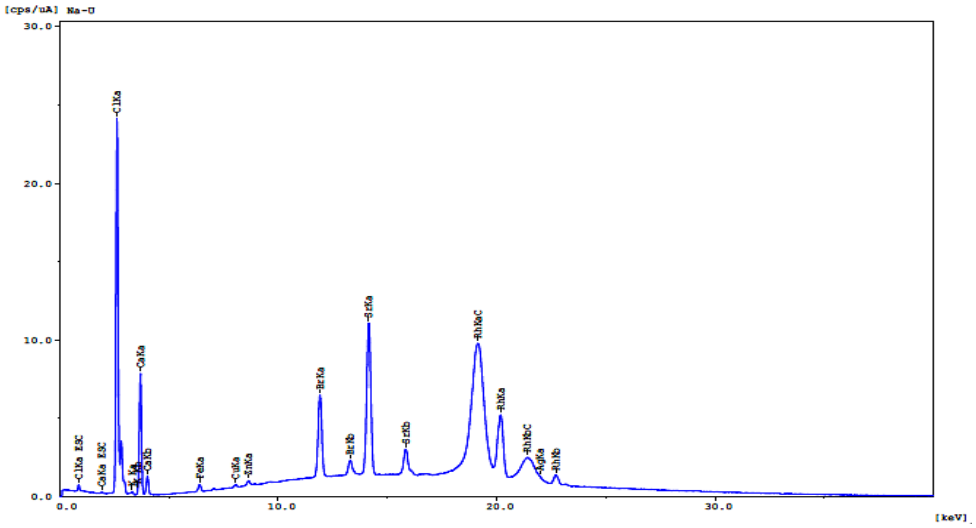


Fig. 10 The spectrum obtained by an X-ray fluorescent analyzer after the separation of the iodine contained in the water

Table 7. Quantitative results obtained by an X-ray fluorescent analyzer after separation of the iodine contained in the water

Analyte	Result (ppm)	Result (%)	[3-sigma]	Proc.-Calc.	Line	Int.(cps/uA)
Cl	132692.8 ppm	13.269	[821.164]	Quan-FP	ClKa	127.6341
Ca	17492.7 ppm	1.749	[183.179]	Quan-FP	CaKa	46.7531
K	812.594	0.081	[94.008]	Quan-FP	K Ka	1.1017
Sr	665.475 ppm	0.066	[4.045]	Quan-FP	SrKa	107.7077
Br	415.986 ppm	0.041	[3.395]	Quan-FP	BrKa	52.4712
Ag	147.550 ppm	0.014	[11.472]	Quan-FP	AgKa	6.1929
Fe	119.047 ppm	0.011	[7.149]	Quan-FP	FeKa	3.3672
Zn	40.771 ppm	0.004	[4.090]	Quan-FP	ZnKa	ZnKa
Cu	24.113 ppm	0.002	[4.094]	Quan-FP	CuKa	1.3216
H_2O	84.759 %	84.759	[------]	Balance	--------	--------

9. Thermal Description

The thermal stability of the extracted complex compound was brought up based on the properties of thermogravimetric curves and mass losses under the influence of temperature. The 7.320 mg deposition of the complex compound was analyzed at temperatures ranging from 33.44 °C to 800.87 °C (Figure 11). This TGA analysis was treated like the TGA and DTA analysis methods in previously performed scientific work [15].

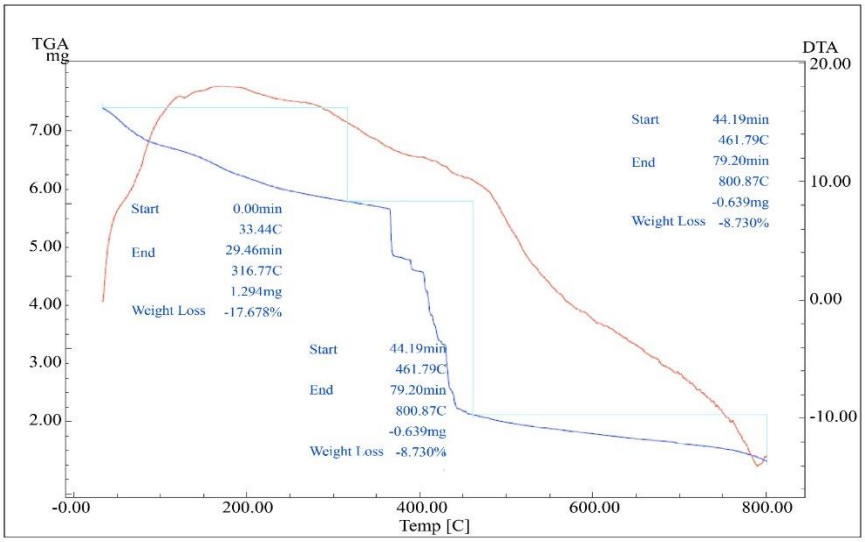


Fig. 11 Thermogravimetric analysis (TGA) of an iodine complex based on diphenylamine from Khaudak groundwater

According to the data, although mass loss occurs mainly in three regions, the first stage itself can be divided into two distinct mass loss events. In the first segment, decomposition of substances was observed in the range of 33.44–110 °C, and in the second segment between 110–316.77 °C, corresponding to weight losses of 0.553 mg (7.555%) and 0.7412 mg (10.125%), respectively. The total weight loss in the first stage was 1.294 mg, accounting for 17.678%. During the first segment of this stage, water bound in the crystal hydrate form was released.

In the second segment, iodine present in the complex was decomposed and separated, accompanied by sublimation of iodine from the sediment. Notably, the iodine transitions to a liquid state before sublimating [16]. The second stage occurred between 316.77–461.79 °C, resulting in a mass loss of 2.939 mg, which corresponds to 40.150%. In this stage, it is evident that the unreacted portion of diphenylamine begins to evaporate at temperatures around 350 °C, along with the decomposition of the diphenylamine-iron complex (Table 8).

The third stage was observed between 461.79 °C and 800.87 °C, with a mass loss of 0.639 mg (8.730%). At this stage, the mass change was relatively small and occurred as a result of the decomposition of certain salts and their complexes into organic compounds, oxides, and water. At high temperatures, mass loss occurred due to the release of CO_2 and SO_2 gases resulting from the gradual decomposition of sulfate and carbonate salts [17, 18]. During the process of iodine precipitation from saline water as a starch-based complex compound, it was observed that the level of iodine absorption depended on the amount of added oxidizing agent and starch solution (Table 9).

Table 8. TGA-based values of mass lost depending on temperature

No.	Temperature, °C	Lost mass, mg (7.320 mg)	Mass lost, %
1	100	0.5198	7,101
2	200	0.9660	13.196
3	300	1.2614	17.232
4	400	2.2567	30.829
5	500	4.3330	59,194
6	600	4.4928	61.377
7	700	4.6279	63.222
8	800	4.8675	66.496

Table 9. Indicators of deposition of iodine based on starch

Saltwater volume (l) and oxidizing volume (ml)	Solvent and concentration of starch	Added solution volume (ml)	The time it takes to form a complex (clock)	Total sediment content (gr)	Iodine content in sediment (%)	Iodine absorption rate relative to initial water (%)
0.5, 2 ml 30 % solution of $FeCl_3$	5 % solution in water (starch clayster)	10	24	0.42	0.866	33.64
0.5, 2 ml 30 % solution of $FeCl_3$	5 % solution in water (starch Clayster)	5	24	0.2	1,7	31.77
0.67, $FeCl_3$ 35 ml 0.2 normal solution	1 % solution in water (starch Clayster)	15	24	0.487	0,98	33.44

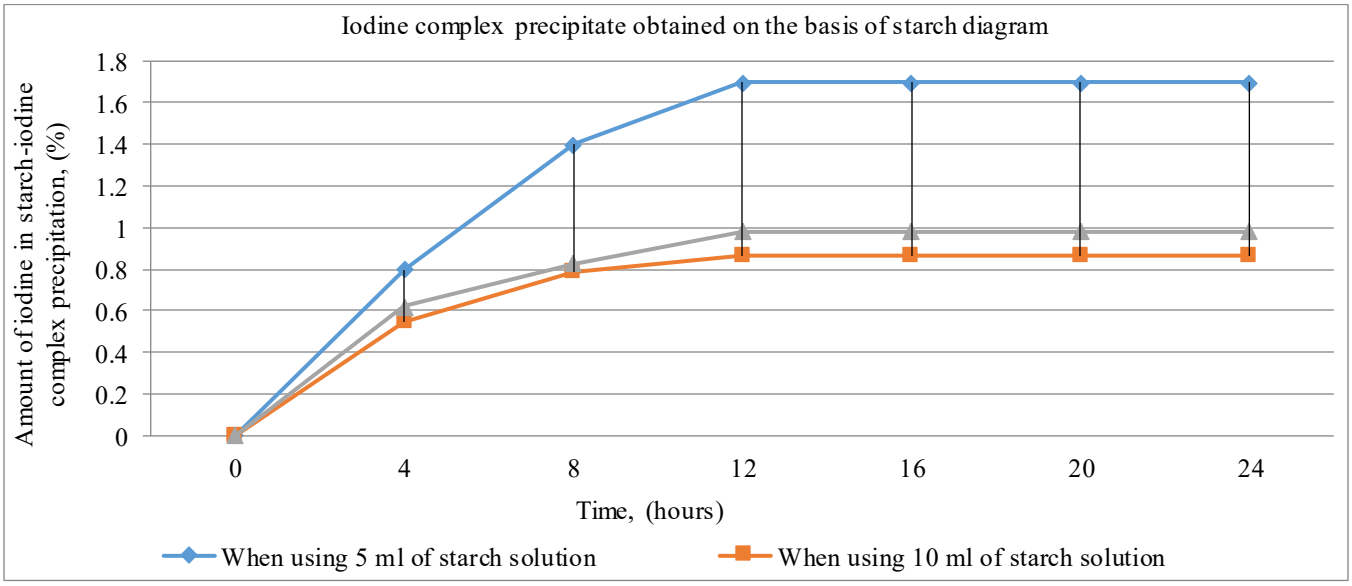


Fig. 12 Diagram of the separation of iodine in water based on starch

The degree of conversion of iodine in water to a compound will depend on the amount of starch solution and time (Figure 12). As shown in the diagram, the complex precipitate formed by the addition of 5 mL of a 5% starch solution to 0.5 L of saline water yielded the highest iodine content, approaching 2%. However, increasing the amount of starch led to a decrease in the iodine content of the precipitate, which was reduced to around 1%. In this case, although iodine binding occurred rapidly at the initial stage, the activity gradually declined, and it can be observed that the process ceased entirely after 12 hours.

Based on the DPA (Dynamic Process Analysis) of iodine in saline water, it is evident that the efficiency of iodine uptake during complex formation depends on the concentration of the added starch and oxidizing agent solutions (Table 10). This table shows that the amount of DPA solution, on average for 0.5 l of salt water, absorbs a high level of iodine when applied 2 ml of a 10% solution is applied. Iodine absorption indicators are reflected in the diagram in Figure 13. This diagram shows the highest absorption rate for iodine chemosorption for 84 hours when an average solution of 2 ml (6 ml of 10% solution per 1.65 ml of water) was applied, calculated for 0.5 l of Khaudak water. The amount of iodine in the extracted complex is about 6%.

The lowest was 7.5 ml of 1 M solution per 0.5 l of water with activity for 60 hours when applied, and the iodine content in the complex sediment was close to 2%. Benzyl alcohol as a solvent in DPA Solutions showed higher productivity than ethyl alcohol. When comparing starch and DPA abilities in the complex separation of iodine in the water of Khaudak, it can be seen that DPA has high efficiency (Figure 14).

According to the diagram, starch demonstrated iodine-binding activity in saline water for approximately 12–24 hours, during which the binding capacity reached about 35%. However, based on DPA (Dynamic Process Analysis), iodine uptake peaked between 60–84 hours, with a binding efficiency exceeding 90% [19-22].

Table 10. Indicators of deposition of iodine based on DPA

Saltwater Volume (l) and oxidizing volume (ml)	Solvent and Concentration of DPA	Volume of Added solution (ml)	Time taken from complex (hours)	Total Sediment amount (g)	Amount of Iodine in sediment (%)	The absorption rate of iodine compared to the initial water (%)
1, 5 ml 30 % solution of $FeCl_3$	10% CH_3CH_2OH solution	10	36	0.245	3,883	44.66
0.5, 2 ml 30 % solution of $FeCl_3$	1 M CH_3CH_2OH solution	4	72	0.293	3.358	92.38
0.5, 2 ml 30 % solution of $FeCl_3$	1 M CH_3CH_2OH solution	7.5	60	0.553	1.709	88.74
1.65, 8 ml 30 % solution of $FeCl_3$	10 % $C_6H_5CH_2OH$ solution	6	84	0.56	5.841	93.04

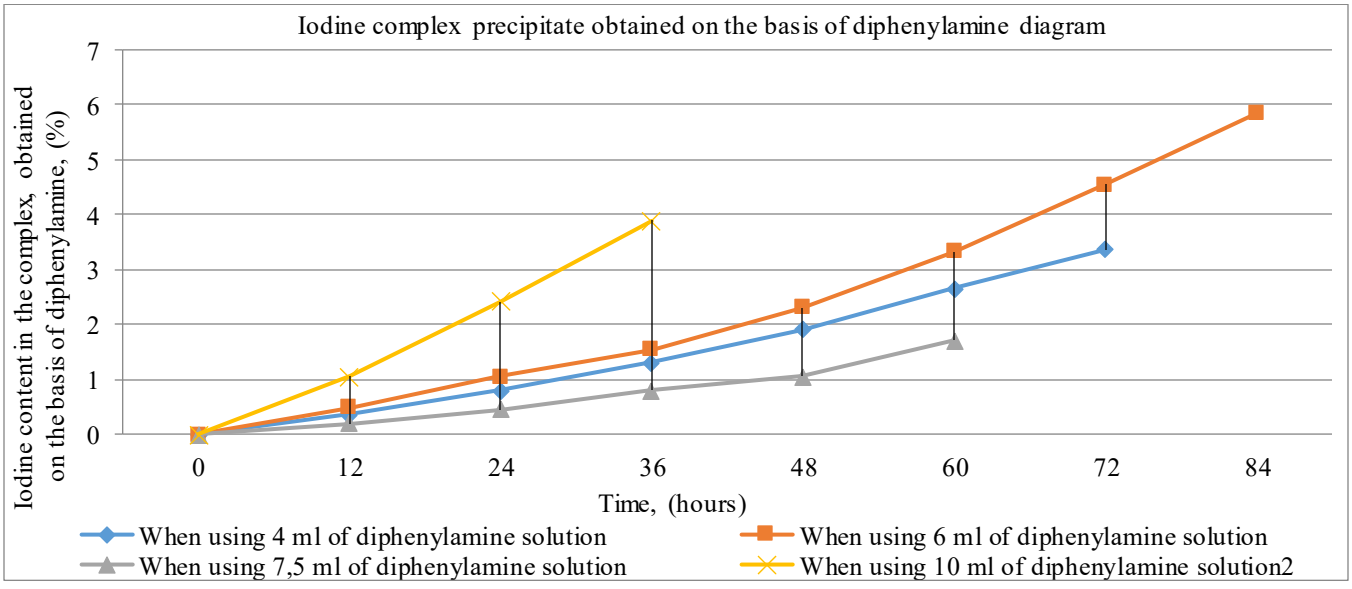


Fig. 13 Diagram of mastering saltwater iodine based on DPA

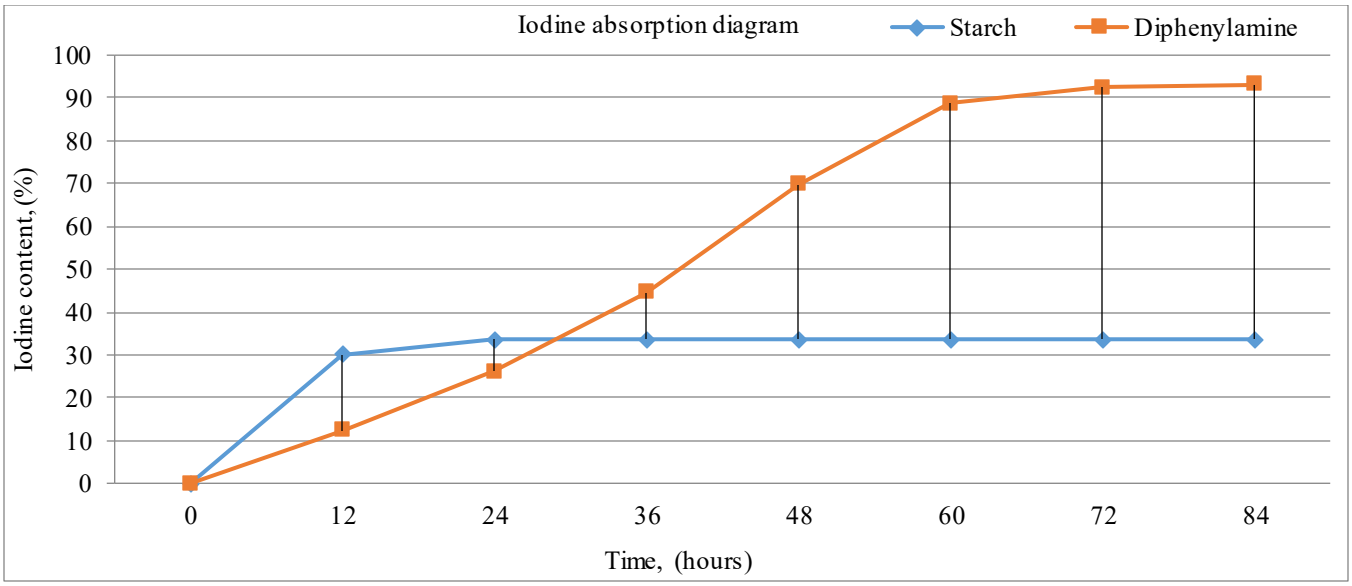


Fig. 14 Comparison diagram of the performance of DPA and starch in absorbing iodine from saline water

10. Conclusion

In this scientific study, the composition of iodine-containing groundwater and the iodine compounds derived from it were investigated using various analytical methods. The ability of starch and diphenylamine to precipitate oxidized iodine from saline groundwater in the form of complex compounds was examined. The duration of complex formation processes varied depending on the amount of reagent added, and optimal conditions were determined accordingly.

Experimental results confirmed that certain ions and starch in the groundwater formed a cross-linked starch–iodine complex, while diphenylamine formed iron–diphenylamine–iodine complexes.

The isolated starch–iodine complex contained 0.866% iodine, corresponding to an iodine removal efficiency of approximately 35%. In contrast, the complex formed using diphenylamine contained 5.841% iodine, with a separation efficiency exceeding 90%. The resulting sediments can be used to produce iodine and iodine-based compounds, offering both environmental and economic advantages through recycling.

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Ethical Clearance

The project was approved by the local ethical committee at Termez State University.

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