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Section 1. Chemistry

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POSSIBILITIES FOR REDUCING THE HARDNESS OF REVERSE OSMOSIS WASTEWATER AND ITS APPLICATION AS A LIQUID FERTILIZER FOR AGRICULTURAL CROPS

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Abstract

This study investigates the possibilities of reducing the hardness of highly mineralized wastewater generated as a result of reverse osmosis (RO) technology and reprocessing it for use as a liquid fertilizer. As the object of the research, wastewater obtained from the RO unit of Soda Workshop No. 3 at JSC "Ferganaazot" was selected. The high concentrations of calcium and magnesium ions in RO wastewater make its direct discharge into the environment environmentally hazardous; however, the presence of potassium and nitrogen-containing compounds turns this water into a promising resource for use as a liquid fertilizer in agriculture.

Since the high hardness of the wastewater limits this possibility, KU-2/8 cation-exchange and AB-17/8 anion-exchange resins were used to reduce hardness. Experiments were conducted under laboratory conditions using individual cation-exchange, anion-exchange, and mixed-bed (FSD) systems. The chemical composition of the water samples was analyzed in terms of pH, total hardness, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO^{3-}, NH^{4+}, K^+, Na^+, and other ions.

The obtained results showed that the KU-2/8 cation-exchange resin reduced total hardness from 42 mg eq/dm³ to 1.25 mg eq/dm³ in the first cycle and effectively removed Ca^{2+} and Mg^{2+} ions. Although the AB-17/8 anion-exchange resin significantly reduced SO_4^{2-} and NO^{3-} ions, it was found to undergo rapid degradation under conditions of strong alkaline regeneration. Using the mixed-bed (FSD) system, total water hardness was reduced to 0.45 mg eq/dm³; however, excessive demineralization of the water led to a decrease in the content of beneficial macroelements.

Keywords: *Reverse osmosis wastewater; ion-exchange resins; KU-2/8 cation exchanger; AB-17/8 anion exchanger; water hardness; mixed-bed (FSD) system; RO concentrate; regeneration*

Introduction

Osmosis technologies, particularly reverse osmosis (RO), are widely used in industrial and municipal water treatment. Although this technology is highly efficient, the wastewater it generates (RO concentrate or brine) may have adverse environmental impacts. RO wastewater is often characterized by high hardness, alkalinity, and elevated concentrations of ions such as sulfates and nitrates, and its direct discharge into natural water bodies can cause damage to ecosystems (Smith, J., et al., 2022, 115–130; Li, X., & Zhao, Y., 2021, 117–125: Nguyen, T., et al., 2020; 122–135., Kumar, R., et al., 2023, 139–152; Chen, L., et al., 2021, 233–245).

However, the composition of RO wastewater includes not only harmful substances but also macroelements beneficial for soil and plant growth, such as potassium (K^+) and nitrogen (NO^{3-}, NH_4^+). Reverse osmosis wastewater has a high ionic concentration, and when used directly for irrigation, elevated levels of Na^+ and SO_4^{2-} may induce stress in plants (Khamdamova, Z. Sh., Sherkuziev, D. Sh., Khamdamov, D. M., 2025, 454–460). Therefore, converting RO wastewater into a liquid fertilizer instead of direct discharge represents a more beneficial and environmentally safe solution for both industry and agriculture (Patel, M., et al., 2022, 58–68; Wang, H., & Li, J., 2020, 1123–1135; Zhang, Q., et al., 2021, 101–112; Das, P., et al., 2022, 4123–4135; Sato, K., & Tanaka, H., 2020, 115–124).

Nevertheless, RO wastewater typically exhibits high hardness (reaching 42 mg eq/dm³ in this study), which limits its application as a liquid fertilizer. High water hardness can negatively affect soil structure and disrupt ionic balance in plants.

Consequently, reducing water hardness is a necessary step before utilizing RO wastewater as a fertilizer (Lee, S., et al., 2023, 345–358; Ahmed, R., et al., 2021, 67–79; Park, D., et al., 2022, 204–215; Silva, C., et al., 2020, 104–115; Huang, Y., et al., 2021, 108–119).

The reduction or elimination of water hardness is currently an important issue from ecological, economic, and sanitary perspectives (Chen, L., et al., 2019, 102–112; Missimer, T. M., 2018, 1–12; Khamdamova, Z. Sh., Sherkuziev, D. Sh., Khamdamov, D. M., 2025, 240–250). As a solution to this problem, attention was focused on ion-exchange resins.

Ion-exchange resins (KU-2/8 cation exchanger and AB-17/8 anion exchanger) were selected to perform this task. These resins effectively remove hardness-forming ions such as Ca^{2+}, Mg^{2+}, and SO_4^{2-} from RO wastewater, thereby reducing water hardness and creating suitable conditions for liquid fertilizer preparation. The research results indicate that although the resins effectively purify the water composition, excessive treatment – namely, the removal of all ions – also reduces beneficial elements such as potassium and nitrogen. As a result, the treated water does not reach an optimal state for use as a liquid fertilizer. In addition, practical limitations were identified, including the degradation of the anion-exchange resin after strong alkaline regeneration and its lack of operational stability (Martinez, A., et al., 2022, 120–132; Roberts, G., et al., 2020, 456–469; Wang, Z., & Chen, X., 2021, 89–101., Kim, S., et al., 2022, 121–132; Johnson, P., & Lee, H., 2023, 102–115).

Thus, in order to reuse RO wastewater as a liquid fertilizer, it is necessary to reduce its hardness; however, the application of ion-exchange methods may remove not only harmful components but also beneficial elements, which requires optimization and a balanced approach. In this context, the present study is aimed at determining an optimal method that enables effective hardness removal from RO wastewater using KU-2/8 and AB-17/8 resins while preserving its suitability for subsequent liquid fertilizer production.

Practical significance

Direct discharge of RO wastewater into the natural environment is harmful; however, reducing its hardness through ion exchange creates favorable conditions for liquid fertilizer production. At the same time, excessive treatment may also eliminate beneficial elements; therefore, identifying an optimal balance is crucial (Patel, M., et al., 2022, 58–68; Wang, H., & Li, J., 2020, 1123–1135; Zhang, Q., et al., 2021, 101–112; Das, P., et al., 2022, 4123–4135; Sato, K., & Tanaka, H., 2020, 115–124; Kim, S., et al., 2022, 121–132; Johnson, P., & Lee, H., 2023, 102–115; Zhang, L., et al., 2021, 116–128., Li, H., & Xu, Y., 2022, 132–145).

Experiments and methods

Experimental Object and Materials Used

Experimental studies were carried out using wastewater (concentrate) generated by a reverse osmosis (RO) unit operating at the Water Treatment and Neutralization Workshop of JSC "Ferganaazot", located in the Fergana region. This wastewater is characterized by high mineralization and elevated concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), and nitrate (NO^{3-}) ions. For this reason, the direct discharge of this wastewater into the environment poses a significant ecological risk.

To perform ion-exchange processes, the widely used industrial ion-exchange resins KU-2/8 (cation exchanger) and AB-17/8 (anion exchanger) were selected. Both resins had a granulometric particle size of 0.315 mm, which ensures efficient mass transfer. Each resin was separately measured in an amount of 50 cm³ and packed into glass columns with a diameter of $d = 25.0 \pm 0.1$ mm and a height of $h \leq 800$ mm. All experiments were conducted under laboratory conditions.

Preparation and Regeneration of Resins

Prior to the experiments, the ion-exchange resins were soaked in distilled water for 8 hours for activation purposes. This step ensured complete swelling of the resin granules and the opening of active ion-exchange sites. After soaking, the resins were carefully loaded into the prepared columns, avoiding the formation of air bubbles.

The packed columns were rinsed with 0.5 L of distilled water at a flow rate of 250 cm³/h in a dropwise mode. This procedure served to remove residual mechanical impurities and contaminants remaining from the manufacturing process.

To restore the ion-exchange capacity of the resins, a regeneration process was carried out under the following conditions:

KU-2/8 cation-exchange resin was regenerated using 100 mL of a 4% sulfuric acid (H_2SO_4) solution;

AB-17/8 anion-exchange resin was regenerated using 175 mL of a 4% sodium hydroxide (NaOH) solution.

The regeneration flow rate was maintained at 250 cm³/h. After regeneration, the resins were rinsed with distilled water until a neutral medium (pH ≈ 7) was achieved. Neutralization was monitored using indicator paper. Upon completion of neutralization, the resins in the columns were kept in a closed state filled with distilled water for 1 hour to ensure the complete completion of the regeneration process.

Figure 1. *Experimental setup and methodologies*

Chemical Analysis Methods

To determine the quality of the water samples treated by the ion-exchange process and to assess changes in the concentrations of major ions, comprehensive chemical analyses were performed. The analyses included the following parameters:

- hydrogen ion concentration (pH);
- total hardness;
- calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions;
- sulfate (SO_4^{2-}), nitrate (NO^{3-}), nitrite (NO_2^-), and ammonium (NH_4^+) ions;
- sodium (Na^+) and potassium (K^+) ions;
- chloride (Cl^-) ions;
- iron (Fe^{3+}) ions.

Water samples collected after each regeneration cycle were gathered separately and analyzed using standard analytical methods.

Potentiometric, complexometric, titrimetric, flame photometric, mercurimetric, and photocolorimetric methods were employed for the analyses. All analyses were carried out at the Central Chemical Laboratory of the "Ferganaazot" plant.

Experimental section and results

Experiments conducted using KU-2/8 cation-exchange resin and AB-17/8 anion-exchange resin were performed by passing reverse osmosis (RO) wastewater (concentrate) from the RO unit of Soda Workshop No. 3 through the resins at a flow rate of 250 cm³/h. Prior to the experiments, the resins were kept in a closed state filled with distilled water for 1 hour.

The first 100 mL of filtrate was discarded, as it was considered non-equilibrated water that had not yet reached ion-exchange equilibrium with the resin. In subsequent stages, the collected filtrates were gathered separately according to volume, and their total hardness and chemical composition were determined.

Table 1. *Total hardness values of water at each stage after treatment with KU-2/8 cation-exchange resin and AB-17/8 anion-exchange resin*

	KU-2/8 Cation-Exchange Resin		**AB-17/8 Anion-Exchange Resin**	
No.	**Volume of water passed through the resin, mL**	**Total hardness, mg eq/dm³**	**Volume of water passed through the resin, mL**	**Total hardness, mg eq/dm³**
1.	50	0.25	50	8,2
2.	100	0.17	100	7,8
3.	200	0.04	200	9,2
4.	200	0.07	200	9,2
5.	300	0.04	200	10,4
6.	500	0.07		
7.	500	0.2		
8.	500	16.9		

The KU-2/8 cation-exchange resin effectively removed Ca^{2+} and Mg^{2+} ions, while the AB-17/8 anion-exchange resin reduced $SO4^{2-}$ and $NO3^-$ ions. During the first cycle, the water hardness was reduced to the target level.

However, since the total hardness values obtained after treatment with the KU-2/8 cation-exchange and AB-17/8 anion-exchange resins exceeded the required threshold, the purification process was stopped. A second regeneration was then carried out following the same regeneration procedure described above. The treated and collected water samples that passed through the KU-2/8 cation-exchange and AB-17/8 anion-exchange resins were subsequently subjected to chemical analysis. The measurement results were recorded in tabular form, and the efficiency of the ion-exchange process was evaluated (Table 2).

Figure 2. *Samples obtained under laboratory conditions*

Table 2. *General analytical parameters of water samples before and after treatment with KU-2/8 cation-exchange resin and AB-17/8 anion-exchange resin*

No.	Parameters	Results		
		Soda Workshop No.3 Wastewater	**KU-2/8 Cation-Exchange Resin**	**AB-17/8 Anion-Exchange Resin**
1.	Hydrogen ion concentration (pH)	7.86	6.07	11.48
2.	Magnesium ions (Mg^{2+}), mg eq/dm^3	17.0	1.05	0.65
3.	Calcium ions (Ca^{2+}), mg eq/dm^3	25.0	0.2	4.85
4.	Total hardness, mg eq/dm^3	42.0	1.25	5.5
5.	Total alkalinity, mg eq/dm^3	22.0	0.3	15.5
6.	Sodium ion mass concentration (Na^+), mg/dm^3	0.13	0.35	0.13
7.	Potassium ion mass concentration (K^+), mg/dm^3	16.3	8.2	15.7
8.	Chloride ion mass concentration (Cl^-), mg/dm^3	31.9	28.36	58.4
9.	Nitrite ion mass concentration (NO_2^-), mg/dm^3	0.0	0.645	0.0
10.	Nitrate ion mass concentration (NO_3^-), mg/dm^3	56.0	34.0	10.0
11.	Ammonium ion mass concentration (NH_4^+), mg/dm^3	0.0	0.0	0.0
12.	Iron (Fe^{3+}) ion mass concentration, mg/dm^3	0.06	0.18	0.07
13.	Sulfate ion mass concentration (SO_4^{2-}), mg/dm^3	1152.0	918.7	1.044

The KU-2/8 cation-exchange resin effectively reduced water hardness, while the AB-17/8 anion-exchange resin increased alkalinity and almost completely removed SO_4^{2-} ions.

Mixed-Bed (FSD) Ion-Exchange System

To achieve deeper water purification and maximize hardness removal, a mixed-bed (FSD – *Filtr Smeshannogo Deystviya*) ion-exchange system was employed. In this stage, water that had passed through the KU-2/8 cation-exchange resin was passed through a column containing freshly regenerated AB-17/8 anion-exchange resin.

In the FSD system, the first 100 mL of filtrate was discarded, as it represented non-equilibrated water that had not yet reached ion-exchange equilibrium with the resin. Subsequently, the filtrates were collected separately according to volume, and their total hardness and chemical composition were determined (Table 3).

Table 3. *Total hardness values of water at each stage after passing through the FSD resin*

No.	Volume of water passed through FSD resin, mL	Total hardness, mg eq/dm³
1.	100	0.13
2.	100	0.174
3.	200	0.18
4.	200	0.38

The mixed-bed (FSD) system reduced the total hardness to a minimum level (0.45 mg eq/dm³), while partially preserving beneficial K^+ and NO_3^- ions.

Table 4. *General analytical parameters of water samples before and after treatment with FSD resin*

No	Parameter	Results	
		Soda Workshop No. 3 Wastewater	FSD resin
1.	Hydrogen ion concentration (pH)	7.86	12.14
2.	Magnesium ions (Mg^{2+}), mg eq/dm³	17.0	0.15
3.	Calcium ions (Ca^{2+}), mg eq/dm³	25.0	0.3
4.	Total hardness, mg eq/dm³	42.0	0.45
5.	Total alkalinity, mg eq/dm³	22.0	19.25
6.	Sodium ion mass concentration (Na^+), mg/dm³	0.13	376.9
7.	Potassium ion mass concentration (K^+), mg/dm³	16.3	13.5
8.	Chloride ion mass concentration (Cl^-), mg/dm³	31.9	124.9
9.	Nitrite ion mass concentration (NO_2^-), mg/dm³	0.0	0.01
10.	Nitrate ion mass concentration (NO_3^-), mg/dm³	56.0	0.43
11.	Ammonium ion mass concentration (NH_4^+), mg/dm³	0.0	0.0
12.	Iron (Fe^{3+}) ion mass concentration, mg/dm³	0.06	0.0
13.	Sulfate ion mass concentration (SO_4^{2-}), mg/dm³	1152.0	43.8

Using the mixed-bed system, a sharp decrease in the concentrations of Ca^{2+} and Mg^{2+} ions, as well as SO_4^{2-} and NO_3^- ions, was observed. At the same time, the high degree of water demineralization indicated the need to assess its suitability for use as a liquid fertilizer.

Experiments conducted after the 2nd, 3rd, and 4th regenerations of the KU-2/8 cation-exchange resin showed that after the 2nd regeneration, the KU-2/8 cation-exchange resin was washed with 330 mL of distilled water until it reached a neutral state. The KU-2/8 cation-exchange resin was then ready for reuse. Subsequently, the wastewater concentrate was passed through the resin again. The first 100 mL of filtrate was discarded. The volume and total hardness of water passing through the resin at each subsequent stage were determined and recorded.

Table 5. *Analysis of total hardness of water passing through KU-2/8 resin after the 2nd regeneration*

No.	Volume of water passed through KU-2/8 cation-exchange resin after 2nd regeneration, mL	Total hardness, mg eq/dm³
1.	50	0.7
2.	100	1.09
3.	300	0.85
4.	200	0.84
5.	200	15.2

The purification process was stopped because the total hardness of water passing through the KU-2/8 cation-exchange resin exceeded the desired value (15.2 mg eq/dm³). A third regeneration was then carried out following the previously described procedure. The treated and collected water (KU2R) passing through the KU-2/8 cation-exchange resin was subjected to chemical analysis.

After the 3rd regeneration, the KU-2/8 cation-exchange resin was washed with 300 mL of distilled water until it reached a neutral state. The resin was then ready for a third use. The wastewater concentrate was passed through the resin again. The first 100 mL of filtrate was discarded. The volume and total hardness of water passing through the resin at each subsequent stage were determined and recorded.

Table 6. *Analysis of total hardness of water passing through KU-2/8 resin after the 3rd regeneration*

No.	Volume of water passed through KU-2/8 cation-exchange resin after 3rd regeneration, mL	Total hardness, mg eq/dm³
1.	100	2.93
2.	100	4.6
3.	200	4.0
4.	250	4.7
5.	300	30.6
6.	100	30.75

The purification process was stopped because the total hardness of water passing through the KU-2/8 cation-exchange resin exceeded the desired value (30.75 mg eq/dm³). A fourth regeneration was carried out following the previously described procedure. The treated and collected water (KU3R) passing through the KU-2/8 cation-exchange resin was subjected to chemical analysis.

After the 4th regeneration, the KU-2/8 cation-exchange resin was washed with 300 mL of distilled water until it reached a neutral state. The resin was then ready for a fourth use. The wastewater concentrate was passed through the resin again. The first 100 mL of filtrate was discarded. The volume and total hardness of water passing through the resin at each subsequent stage were determined and recorded.

Table 7. *Analysis of total hardness of water passing through KU-2/8 resin after the 4th regeneration*

No.	Volume of water passed through KU-2/8 cation-exchange resin after 4th regeneration, mL	Total hardness, mg eq/dm³
1.	100	4.1
2.	100	4.25
3.	200	4.3
4.	300	6.0
5.	300	17.5

The purification process was stopped because the total hardness of water passing through the KU-2/8 cation-exchange resin exceeded the desired value (17.5 mg eq/dm³). The treated and collected water (KU 4 R) passing through the KU-2/8 cation-exchange resin was subjected to chemical analysis.

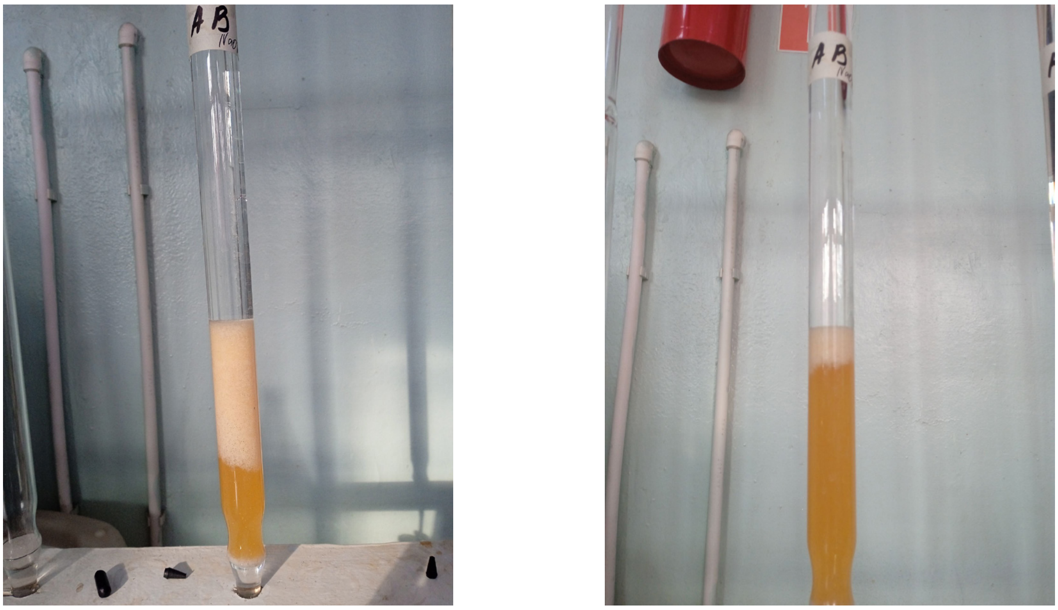
Table 8. *General analytical parameters of water samples before and after passing through KU-2/8 resin (KU 2 R, KU 3 R, KU 4 R)*

No.	Parameter	Results			
		Soda Workshop No. 3 Wastewater	KU 2 R	KU 3 R	KU 4 R
1.	Hydrogen ion concentration (pH)	7.86	1.81	2.16	2.02
2.	Magnesium ions (Mg^{2+}), mg eq/dm³	17.0	1.75	7.5	3.1
3.	Calcium ions (Ca^{2+}), mg eq/dm³	25.0	0.9	7.0	4.5
4.	Total hardness, mg eq/dm³	42.0	2.65	14.5	7.6
5.	Total alkalinity, mg eq/dm³	22.0	0.0	0.0	0.0
6.	Sodium ion mass concentration (Na^+), mg/dm³	0.13	0.07	116.6	133.9
7.	Potassium ion mass concentration (K^+), mg/dm³	16.3	3.7	12.8	10.7
8.	Chloride ion mass concentration (Cl^-), mg/dm³	31.9	26.5	24.8	26.5
9.	Nitrite ion mass concentration (NO_2^-), mg/dm³	0.0	0.4	0.3	0.66
10.	Nitrate ion mass concentration (NO_3^-), mg/dm³	56.0	0.2	0.0	0.0
11.	Ammonium ion mass concentration (NH_4^+), mg/dm³	0.0	0.0	0.0	0.0
12.	Iron (Fe^{3+}) ion mass concentration, mg/dm³	0.06	0.037	0.063	0.063
13.	Sulfate ion mass concentration (SO_4^{2-}), mg/dm³	1152.0	814.0	887.4	887.4

Second Regeneration of AB-17/8 Anion-Exchange Resin

After the 2nd regeneration, the AB-17/8 anion-exchange resin changed color, and a sludge-like mass formed inside it. To reuse the resin, it needed to be washed until it reached a neutral state. The resin was washed with 7.5 liters of distilled water over a period of two weeks. However, the resin did not return to a neutral state and became unusable.

Figure 3. *Experimental Procedure*



The results showed that the KU-2/8 cation-exchange resin reduced total hardness from 42 mg eq/dm^3 to 1.25 mg eq/dm^3 in the first cycle and effectively removed Ca^{2+} and Mg^{2+} ions. The KU-2/8 resin remained effective for up to four cycles. The AB-17/8 anion-exchange resin efficiently removed SO_4^{2-} and NO_3^- ions, but underwent rapid degradation at high pH (Zhang, L., et al., 2021; Li, H., & Xu, Y., 2022; Kumar, A., et al., 2020; Chen, Y., et al., 2022).

In the FSD (mixed-bed) system, water passing through the KU-2/8 cation-exchange resin and then through the AB-17/8 anion-exchange resin reached a total hardness of 0.45 mg eq/dm^3. At the same time, K^+ and NO_3^- ions were partially retained, maintaining the possibility of using the water as a liquid fertilizer.

Conclusion

KU-2/8 cation-exchange and AB-17/8 anion-exchange resins effectively reduced the hardness of RO wastewater. The mixed-bed (FSD) system decreased total hardness from 42 mg eq/dm^3 to 0.45 mg eq/dm^3, while partially preserving beneficial elements (K^+ and NO_3^-). The AB-17/8 anion-exchange resin degraded after strong alkaline regeneration. The FSD system also led to a sharp reduction in Ca^{2+}, Mg^{2+}, SO_4^{2-}, and NO_3^- ions. However, extensive demineralization highlighted the need to evaluate the water's suitability for use as a liquid fertilizer.

Reducing hardness is necessary to convert RO wastewater into liquid fertilizer, but excessive purification can reduce the content of beneficial elements. The study results indicate that the ion-exchange method effectively decreases the hardness of RO wastewater. For producing liquid fertilizer, it is important not to remove all ions, but to maintain an optimal balance, which requires the development of a technologically balanced approach.

The findings have significant scientific and practical importance for the environmentally safe recycling of RO wastewater and its utilization as a resource. Current and future studies are focused on implementing optimal strategies for converting RO wastewater into liquid fertilizer.

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STUDYING THE EFFECT OF SYNTHESIZED POLYCARBOXYLATE SUPERPLASTICIZER ON CEMENT STONE AND CEMENT PASTE

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Abstract

As a result of the rapid development of the construction industry, there was a widespread need for plasticizers used for various purposes. However, such shortcomings as high cost and complex synthesis process have limited the widespread use of modern superplasticizers. In this article, we conducted an experimental study of a highly effective superplasticizer based on polycarboxylate. Using a special process, monomer, and macronomer, a new superplasticizer based on polycarboxylate was synthesized. The results showed low cost and high efficiency, indicating the possibility of using this new superplasticizer in high-quality concrete. Furthermore, it was shown that commercial concrete with the addition of this plasticizer loses less than 15% of its cone sediment within 2 hours.

Keywords: *Polycarboxylate superplasticizer, macromanometer, monomer, concrete mix, cement, flowability, flexural and compressive strength*

1. Introduction

Polycarboxylate superplasticizer has now become the most important product in the concrete mix market due to its remarkable advantages, such as high water reduction rate, better compatibility with cement, and better precipitation protection indicators (Huang X. Q., Li X. R., Zhang D. W., et al., 2017). The market demand for polycarboxylate superplasticizer is growing with the planning and implementation of projects in the field of atomic energy, water conservation, the construction of bridges, tunnels, and other major infrastructure, especially railway passenger lines. Polycarboxylate superplasticizer is a unique surfactant whose molecules contain carboxyl-bonded copolymers. Due to this unique molecular structure, it possesses many remarkable properties: low utilization, rapid reduction of water content, significant increase in strength at the initial stage, good preservation of bending, absence of retarding agents, minimal effect on concrete shrinkage, and the addition regime does not affect its effectiveness (Tian W., Liu X. J., Fan L., 2016; Xu C., Huang Y. Q., Weng W. X., et al., 2011). With the development of the economy and the diversification of infrastructure projects, higher demands are placed on the effectiveness of polycarboxylate superplasticizers (Sakai, Etsuo, Ishida, et al., 2006). At the same time, due to the deterioration of the quality of cement, sand, gravel, and other materials in the market, the use of polycarboxylate superplasticizers becomes very sensitive to changes in the quality of concrete raw materials. Especially in winter, during low-temperature construction, the phenomenon of slow water separation in concrete with polycarboxylate superplasticizer is very common, which places even higher demands on the effectiveness of polycarboxylate superplasticizers (Li C. Z., Wang D. M., Song S. M., et al., 2005; Jiang J. Y., Gai G. Q., Kong L. W., et al., 2015). Currently, water-reducing agents available in the market cause early bleeding due to their high water reduction rate, while the stability of the retarding agent requires the development of a substance capable of effectively blocking concrete with high water retention capacity and stable flowability. In this work, starting with the molecular structure design

Song Z. B., Yao Y., Li T., et al., 2017; Li S., Wen Z. Y., 2009; Song Z. B., 2016; Chen M., 2015; Ismoilov F. S., Djalilov A. T., Karimov M. U., 2023), polycarboxylic acid molecule can effectively retain concrete by introducing a glucose ether structure into the polycarboxylic acid molecular chain and replacing the glucose ether structure with phosphate, amine, and carboxylate structures. Moisture controls the hydrolysis rate of the ether group, preventing bleeding while maintaining stable concrete flowability.

Methodology

When synthesizing a polycarboxylate superplasticizer based on HPEG, 180 liters of distilled water are added to a stainless steel reactor, the solutions added to reactor 1 are mixed with 120 g of HPEG, 12 g of acrylic acid, and 0.6 g of mercaptopropionic acid per 180 gr of water and stirred at a rate of 50 times/min until a homogeneous mass is achieved, and the supply from the first reactor to the second reactor continues for 2 hours using a special pump designed for 3–4 hours, resistant to the chemical environment. Reactor 2 is constantly stirred up to 100 times/min. After loading the reagents from part 1 into reactor 2, we introduce a 60% hydrogen peroxide solution from another inlet of reactor 2 into the reaction mixture for 40 minutes. After the hydrogen peroxide solution is finished, stir for 45 minutes. During the synthesis process, a copolymerization reaction of monomers occurs. The dry residue content and pH of the resulting product are determined.

Table 1. *Amount of substances for superplasticizer synthesis*

No.	Substances used in synthesis	Quantity (g)
	1 partial solution	
1.	HPEG	**120**
2.	water	**180**
3.	acrylic acid	**12**
4.	MPA-3: 95%	**3.6**
	2 – partial solution	
5.	Water	**180**
6.	APS 99%	**0.5**

Result and analysis

Currently, cement concrete remains the main building material, therefore, the problems of increasing its technological strength and durability remain relevant. Among the additives widely used in concrete and reinforced concrete production, plasticizers occupy the first place.

The dependence of HPEG-based polycarboxylate superplasticizer yield on time is presented in Figure 2. As can be seen from Figure 2, the highest profitability compared to others is obtained when the ratio of acrylic acid to HPEG is 8:1. The synthesis process takes 5 hours. In an experiment lasting more than 5 hours, the superplasticizer yield decreases. This can be explained by the fact that the substances taken for raw materials are in various aggregate states for 5 hours or more. Because the presence of interacting substances in two different states of aggregation reduces their interaction.

Figure 1. *HPEG-based polycarboxylate superplasticizer dependence of productivity on time*

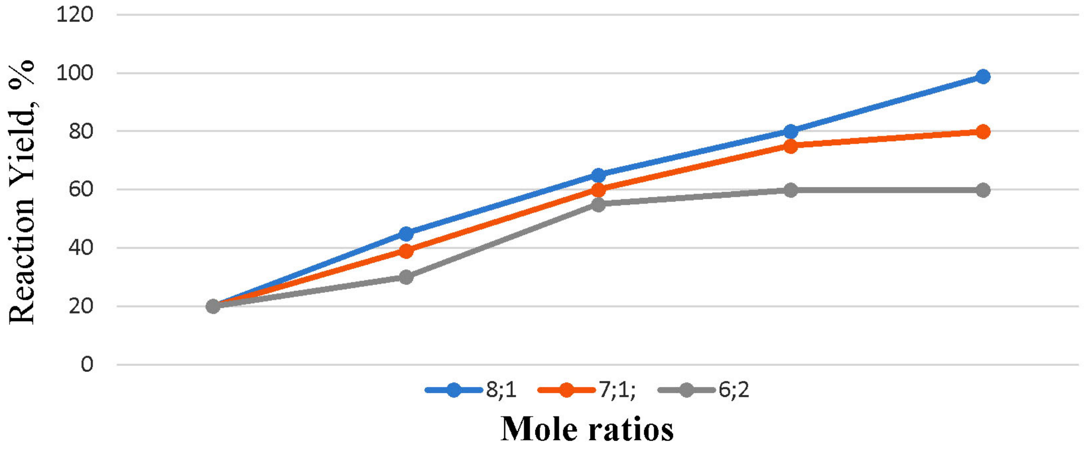


Figure 2. *Dependence of the yield of HPEG-based polycarboxylate superplasticizer on the molar ratio*

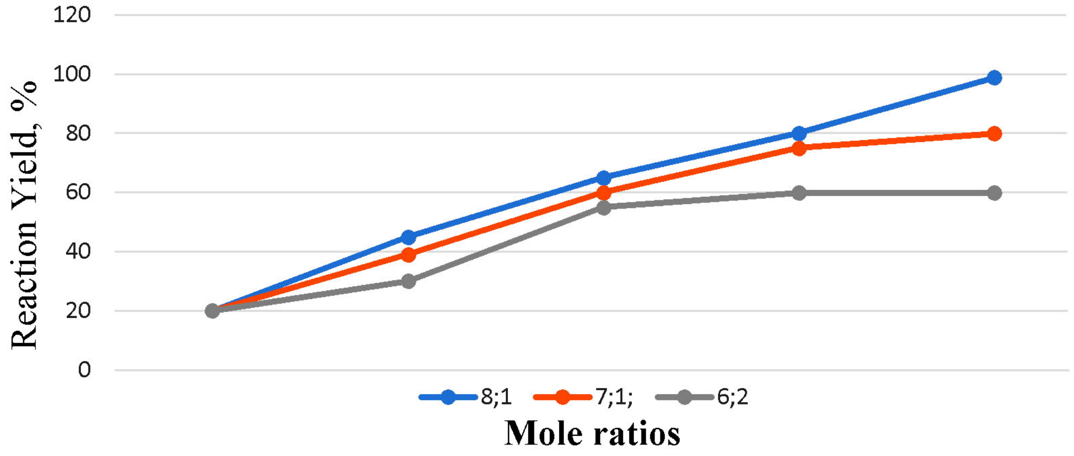


Figure 2. Dependence of the yield of a polycarboxylate superplasticizer obtained on the basis of HPEG on the molar ratio of acrylic acid and HPEG As can be seen from Figure 2, the optimal ratio of components in the production of a polycarboxylate superplasticizer is 8:1, while the profitability of the superplasticizer is 90%. The highest dry residue is obtained at a ratio of the initial products 7:1 and 6:2, but the plasticizing effect of the obtained superplasticizers is low. Reaction time also plays an important role in the production of superplasticizers. To choose the optimal reaction yield temperature, all three initial product ratios were selected. As can be seen from the figure, as a result of carrying out the reaction under optimal conditions for 5 hours, a 90% yield of superplasticizer is obtained. Under such conditions, further continuation of the reaction leads to a decrease in yield. This is due to the intensification of parallel reactions (for example, binding, decomposition, intermolecular interaction) leading to a decrease in the plasticizing effect of superplasticizing additives.

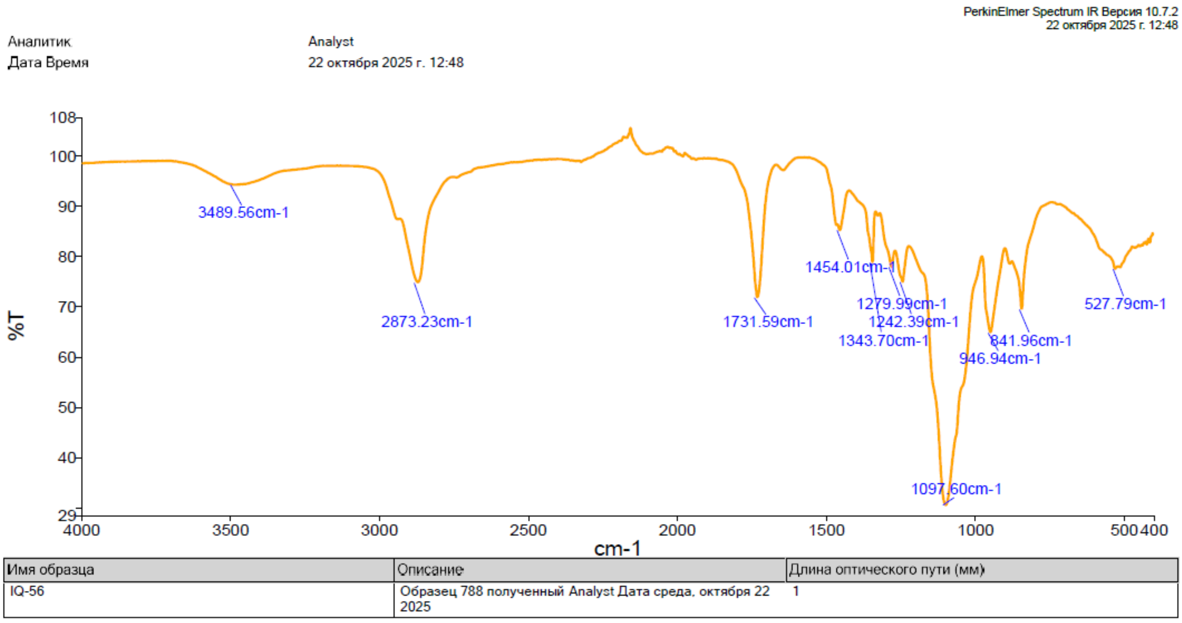
Table 2. *Influence of the molar ratio of substances and time on product yield*

No.	Mass ratios	Time	Reaction Yield, %	No.	Mass ratios	Time	Reaction Yield, %
1.	3:1	2	26.2	11	3:1	4	49.4
2.	4:1		37.3	12	4:1		65.8

No.	Mass ratios	Time	Reaction Yield, %	No.	Mass ratios	Time	Reaction Yield, %
3.	6:2	3	47.4	13	6:2	**5**	72.5
4.	7:1		54.3	14	7:1		78.7
5.	9:1		56.5	15	9:1		**79.8**
6.	3:1		35.5	16	3:1		49.5
7.	4:1		60.5	17	4:1		65.9
8.	6:2		70.5	18	6:2		72.6
9.	7:1		72.4	19	7:1		78.7
10.	9:1		75.5	20	9:1		90

Table 2 presents the influence of various factors on the superplasticizer yield based on the presented results: time and molar ratios of the initial substances. As can be seen from Figure 2, compared to others, the allyllicidal ether is obtained at the highest 8:1 ratio of acrylic acid and HPEG, but the resulting product contains derivatives of di-naphthylsulfones. Therefore, when studying the plasticizing effect of mono-, di-, and other polyhydric alcohols, their derivatives are of particular importance. From the obtained results, it can be seen that the yield of superplasticizer was highest at an allyllycidyl ether, acrylic acid, and HPEG ratio of 8:1 and a process duration of 5 hours.

Figure 3. *IR spectrum of the HPEG-based polycarboxylate superplasticizer*


PerkinElmer Spectrum IR Версия 10.7.2
22 октября 2025 г. 12:48

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IR spectrum: 3489 cm^{-1} (O-H); 1731 cm^{-1}, (C=O); 1097 cm^{-1} (C-O-C); 1343 cm^{-1} (C-O) It can be seen that the resulting low-flow polycarboxylate superplasticizer contains various functional groups such as hydroxyl groups, carbonyl groups, ether groups, and alkyl groups in its molecule, which are essentially consistent with the developed structure. The structure of the obtained product largely corresponds to the molecular structure of the initially developed polycarboxylate superplasticizer.

The hydration of the binding substances showed the presence of a small amount of water, i.e., as a result of drying the samples under natural conditions, a large number of small crystals are formed. Mechanical mixing is carried out using an aqueous solution of polycarboxylate, which improves the wetting properties of cement stone to provide the binder with the necessary amount of water.

Table 3. *Chemical composition of HPEG-based polycarboxylate superplasticizer based on elemental analysis*

Element	Mass%	Energiya spektrometri	Atom%
C	55.17±0.04	K	62.36±0.05
O	43.96±0.09	K	37.30±0.08
S	0.21±0.00	K	0.09±0.00
Total	**100.00**		**100.00**

Table 4. *Technical requirements for HPEG-based polycarboxylate superplasticizer*

Name of indicators	Units of measurement	In solution form
Appearance	%	Light yellow liquid
Density 20 ˚C,	g/sm^3	1.05
Dry residue,	%	30%
Hydrogen ion activity indicator (Ph), aqueous solution	%	7
Dry matter does not exceed the mass fraction of chlorine ions	%	0.10
Water solubility 20 ˚C,	%	Completely dissolves
Reduce water consumption	%	30–35

This method is based on measuring the spread diameter of cement mortar under the influence of gravity. The effects of superplasticizers on cement mixtures were studied, and a superplasticizer based on HPEG was selected. The additives were introduced as aqueous solutions. The concentration of additives was calculated as a percentage ratio of the dry matter mass to the mass of the dispersed phase. Measurements were taken after mixing the solution for two minutes. The setting times of the cement mortar were determined in accordance with GOST 310.3–76. The effect of superplasticizers on concrete strength was investigated using 2 × 2 × 2 sm samples. The specimens were cured under room conditions for 28 days, after which they underwent compression testing.

The effect of superplasticizer on concrete strength was determined using a press (GOST 8905–73) in accordance with GOST 10180–90. The influence of additives on the flowability of concrete mixtures was assessed using a standard slump cone as per GOST 10181.1–– 2000. The cone is filled with the concrete mixture being tested and compacted. After lifting the cone, the spread of the concrete mixture is measured with a measuring device to an accuracy of 0.5 sm. Concrete strength was determined on 10 × 10 × 10 cm samples at 28 days of age. Six samples are prepared for each test. The concrete mixtures are compacted on a type 435A vibrating table.

Table 5. *Results of determining the flowability and average density of cement mortar with the addition of a polycarboxylate-based superplasticizer*

No.	Cement quantity, gr	Cement mass addition,%	Water/cement ratio	Flowability, sm	Average density, gr/sm^3
1.	100	–	0.43	6	1.950
2.	100	0.2	0.42	8.5	1.950

No.	Cement quantity, gr	Cement mass addition,%	Water/cement ratio	Flowability, sm	Average density, gr/sm^3
3.	100	0.4	0.42	10	1.900
4.	100	0.6	0.42	11	1.855
5.	100	0.8	0.42	12	1.850
6.	100	1	0.42	13	1.850

Typically, superplasticizers are added to concrete mixtures in quantities ranging from 0.2% to 0.8% of the cement mass. Adding a plasticizer above 1% is considered impractical. In the experiments, PS400D20 grade cement was used. The flowability of the cement mortar was studied according to GOST 26798.1–96. When studying the physical and mechanical properties of concrete, the water-cement ratio typically ranges from 0.2–0.8%, but at this amount of water, the change in cement spreadability is insignificant. Therefore, to objectively study the rheological properties of cement systems, we selected a water-cement ratio of 0.42.

As can be seen from Table 5, relatively high strength can be achieved by adding a polycarboxylate superplasticizer in an amount of 1%.

Table 6. *The effect of polycarboxylate superplasticizer on the water-cement ratio and strength of the cement system*

No.	Cement quantity, gr	Cement mass addition,%	Water/cement ratio	Strength, MPa
1.	100	–	0.24	18
2.	100	0.2	0.23	24
3.	100	0.4	0.23	29
4.	100	0.6	0.25	33
5.	100	0.8	0.22	36
6.	100	1	0.22	35

Further increase in the amount of polycarboxylate superplasticizer additive reduces the strength of the cement stone. The same effect is observed when adding a polycarboxylate superplasticizer. When this additive is introduced at 0.8%, the strength of the cement stone reaches 36 MPa. With the addition of polycarboxylate superplasticizer, the strength of the cement stone increases as the amount of additive increases. As evident from the above, the obtained polycarboxylate superplasticizer demonstrates good plasticizing properties.

Conclusion

The optimal ratios of HPEG and AK for the synthesis of a new experimental polycarboxylate superplasticizer have been determined. The optimal dose of initiators during the synthesis process was 1.0% of the total mass of monomers and was continuously added dropwise. The concentration of the synthesized superplasticizer was 35%, the reaction temperature ranged from 70 °C to 80 °C, and the reaction time was four hours. A highly effective polycarboxylate superplasticizer with a molecular structure containing carboxyl groups has been synthesized. The newly synthesized superplasticizer has a positive effect on cement compositions, reducing the water demand of the mixture by 15–25% due to high plasticization, while increasing strength properties by 15–25% and density.

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CORRECTION OF METABOLIC AND MORPHOLOGICAL DISORDERS IN EXPERIMENTAL ATHEROCALCINOSIS

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Abstract

This study examined the efficacy of a combination of plant extracts and the reference drug Rosuvastatin Agio in a rabbit model of experimental atherosclerosis. The condition was induced by administering atherogenic substances (cholesterol and vitamin D2) for three months, resulting in severe hypercholesterolemia and pronounced aortic arch atherocalcinosis. The results showed that 30-day use of the plant extract resulted in more pronounced lipid profile normalization than Rosuvastatin: total cholesterol decreased by 89%, and the atherogenicity index decreased from 23.0 to 2.7. Histological analysis confirmed the therapeutic efficacy, manifested in the regression of calcification foci and restoration of the structural order of vascular wall layers. Both therapies promoted normalization of blood glucose levels. These data demonstrate the high hypolipidemic and antiatherosclerotic potential of the studied extract.

Keywords: *experimental atherosclerosis, atherocalcinosis, plant extract, rosuvastatin, lipid profile, total cholesterol*

Introduction

Atherosclerosis remains one of the most serious medical and social problems of the 21st century, being the primary pathogenetic factor in the development of cardiovascular diseases such as coronary heart disease and myocardial infarction. The disease is characterized by chronic inflammation of the vascular wall, dyslipidemia, and the formation of atherosclerotic plaques, which leads to gradual occlusion of the arterial lumen and hemodynamic impairment.

Despite significant advances in modern pharmacology in lipid profile correction (in particular, the use of statins), the search for alternative and complementary treatments remains urgent. This is due to the side effects of synthetic drugs, as well as the need for a comprehensive approach to address various pathogenesis factors:

oxidative stress, inflammation, and endothelial dysfunction.

In this context, phytoextracts with high bioavailability and a polyvalent mechanism of action are of particular interest. Alfalfa (*Medicago sativa*): known for its high content of saponins and flavonoids, which can bind cholesterol in the intestine and reduce its levels in the blood. Hibiscus (*Hibiscus sabdariffa*): rich in anthocyanins and organic acids, which exhibit pronounced antioxidant properties and promote vasodilation. Anise (*Pimpinella anisum*): contains essential oils (anethole), which have anti-inflammatory potential and the ability to modulate metabolic processes.

Histological examination is the "gold standard" for assessing the effectiveness of anti-atherosclerotic therapy, as it allows visualization of morphological changes in the vascular wall, the degree of lipid infiltration, and the preservation of the structural components of the intima and media.

The aim of this study is to comparatively evaluate the effects of alfalfa, hibiscus, and anise extracts on the morphofunctional state of the aorta and the dynamics of atherosclerotic changes in experimental hyperlipidemia.

Materials and Methods

Objects of study: Alfalfa (*Medicago sativa*), Hibiscus (*Hibiscus sabdariffa*), Anise (*Pimpinella anisum*), plants growing in the mountainous regions of Uzbekistan.

Rosovustatin Agio, produced by the Indian company Agio Pharmaceuticals Ltd., was used as a comparison drug.

Extraction technology. Samples of crushed Hibiscus Sabdariffa raw materials (dried petals) and Pimpinella anisum were placed in an enamel container, filled with water in a ratio of 1:10, covered with a lid, and extracted for 60–90 min at a temperature of 60 °C. Then, the extract was filtered and freeze-dried. 25 g of dried crushed dry mass of Medicago sativa L. herb was placed in a two-necked flask and poured with 500 ml of distilled water, extracted for 1.5 hours at a temperature of 70ºC. Then, the extract was filtered. A second stage of extraction was carried out under the same conditions for 45 min, the extracts were combined, evaporated on a rotary evaporator, and freeze-dried.

Atherosclerosis model. The animals were administered crystalline cholesterol (STOCK-MED MCHJ, China) in a dose of 200 mg/kg in cottonseed oil in a volume of 4.0–4.5 ml using an automatic pipette for a long period (3 months). After 1 month of cholesterol administration, vitamin D2 (ergocalciferol), a 0.0625% solution in oil, was added to the animals' diet at a dose of 0.256 ml/kg for 30 days to enhance aortic lipidosis. In order to enhance sclerotic changes in the aorta and reduce the time of atherosclerosis induction, 1 month after the start of cholesterol administration and for the next 30 days, the animals were administered adrenaline at a dose of 0.04 mg/kg of body weight intravenously every 5 days (i.e., 6 injections). After three months, the surviving animals were divided into three groups: Group 1 (control) received water orally, Group 2 received a combination of extracts at a dose of 40 mg/kg, and Group 3 received the reference drug Rosuvastatin-Adgio at a dose of 0.4 mg/kg for 30 days. At the end of the experiment, the animals were transferred to the Republican Pathological Anatomy Center in Tashkent for histological examination of their organs and vessels.

Blood was collected dropwise from the rabbit's ear vein into microtubes over time. A study of the baseline parameters was conducted after 3 months of challenge and after 15 and 30 days of treatment of the following parameters: total protein, glucose, lipid spectrum: triglycerides (TG), total cholesterol (TC), high-density lipids (HDL), low-density lipids (LDL), on a biochemical analyzer using kits from CYPESS DIAGNOSTICS (Germany).

The content of very low density lipoprotein cholesterol (VLDL, mmol/l) and the atherogenic coefficient of cholesterol (AC_{xc}, O.U.) were calculated using the Friedwald formula:

$$AC_{xc} = \frac{TC - HDL}{HDL}, \quad VLDL = \frac{TG}{5}, \quad (1)$$

total protein, glucose, lipid profile: triglycerides (TG), total cholesterol (TC), high-density lipids (HDL), low-density lipids (LDL), very low-density lipoproteins (VLDL), and cholesterol atherogenic index (CAI)

Statistical analysis. All data were presented as mean ± standard error of the mean (SEM). Statistical analyses were performed using R software (version 4.4.2; R Core Team, 2024) with the necessary statistical packages. Descriptive analysis was used to summarize the parameters. Inferential statistics, specifically Student's t-test, were conducted to compare the means of parameters between the control and CE groups, with a significance level of p-value < 0.05. Analyses across time periods were performed for water and food intake using appropriate statistical tests based on the assumptions of each dataset.

Results and discussions

Table 1 presents the results of studies of biochemical parameters of rabbit blood on the cholesterol model.

Table 1. *Blood biochemical parameters of rabbits administered atherogenic substances and after treatment with extracts and rosuvastatin in a rabbit model of atherosclerosis (M ± m, n = 4)*

Tests	**Exodus**	**Treatment of baiting, month**		**Treatment duration, days**			
				Composition of extracts		**Rosuvastatin**	
		2	**3**	**15**	**30**	**15**	**30**
Total protein, g/l	85,2±4,2	90,0±6,0	83,0±6,2	85,0±4,4	86,0±4,6	86,0±4,4	84,0±4,4
Glucose, mmol/l	4,0±0,2*	5,1±0,2*	5,8±0,3*	4,2±0,3#	4,2±0,3 #	4,6±0,4#	4,2±0,3#
TC, mmol/l	2,4±0,2	19,4±1,5*	25,4±1,8*	8,1±0,6*#	2,8±0,2#	9,2±0,6#*	7,8±0,6#*
TG, mmol/l	1,6±0,1	6,8±0,5*	8,1±0,6*	2,3±0,2*#	2,0±0,2*#	3,6±0,2*#	4,1±0,6*#
VLDL mmol/l	0,32±0,02	1,36±0,12*	1,6±0,14*	0,46±0,03*#	0,4±0,03*#	0,72±0,05*#	0,82±0,03*#
LDL, mmol/l	0,38±0,03	1,6±0,10*	2,66±0,12*	0,33±0,02#	0,40±0,02#	0,38±0,02#	0,32±0,02#
HDL, mmol/l	0,76±0,06	1,1±0,08*	1,1±0,08*	0,85±0,06#	0,75±0,06#	0,72±0,05#	0,81±0,06#
AC_{xc}	2,2 ±0,18	16,6±1,34*	23,0±1,7*	8,5±0,64#*	2,7±0,64#*	11,8±1,3*#	8,7±0,64#*

*Note: *p ≤ 0.001 relative to outcome. #p ≤ 0.001 relative to control*

Administration of atherogenic substances for 2 and 3 months resulted in significant changes in the lipid profile and carbohydrate metabolism: The atherogenic index (AOX) in the control group increased sharply from 2.2 to 23.0, confirming the successful creation of a model of severe atherosclerosis.

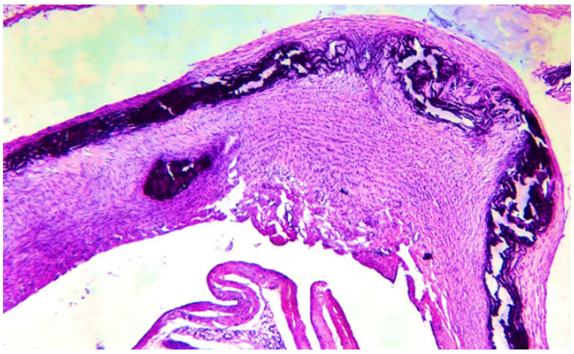
In the experimental group, after 15 days of using the extract composition, the TC indicator decreased by 3.1 times compared to the 3-month control (p ≤ 0.001), and after 30 days, it was not significantly different from the baseline. TG and VLDL decreased by 3.5 and 4.1 times, respectively, compared to the control after 15 and 30 days. AOX decreased by 2.7 times after 15 days of treatment, and after 30 days, TG, VLDL, and AOX approached baseline values. Treatment with Rosuvastatin for 15 and 30 days resulted in a 2.8- and 3.3-fold reduction in TC levels, and a 2.3- and 2.0-fold reduction in TG and VLDL levels, respectively, compared to control levels. AOX decreased by 2.0 times after 15 days of treatment and by 2.6 times after 30 days.

Thus, the therapeutic effect of the extract on the 30th day almost completely normalized the lipid profile of rabbits with cholesterol-induced atherosclerosis, and AOX approached baseline values. Rosuvastatin also had a positive effect on lipid profile, but TC and TG levels remained 2–3 times higher than baseline values. According to the table, the extract composition demonstrated a more pronounced and rapid normalization of total cholesterol levels and the atherogenic index compared to rosuvastatin over this period (30 days). All changes after treatment were highly significant ($p \leq 0.001$) compared to the control group ("treatment").

Under the conditions of this experiment, the plant extract demonstrated a more pronounced ability to reduce total cholesterol and normalize the atherogenic index compared to rosuvastatin by day 30 of treatment.

Histological studies were conducted on control and experimental animals. Figure 1 shows the histopathological morphological picture of aortic arch atherosclerosis in a control animal.

Figure 1. *Aortic arch of a rabbit in which atherosclerosis was induced by administration of cholesterol powder and vitamin D2. General appearance of large foci of atherocalcinosis in the aortic arch at low magnification (Size: 10 × 4. Staining: Hematoxylin-Eosin)*



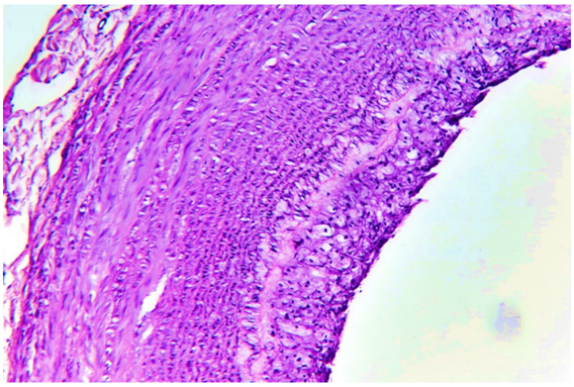
Large foci of atherocalcification are detected in the vessel wall. These calcifications are clearly located in the tunica media (middle layer) of the vessel. Massive plaques protruding into the lumen are visible, almost blocking blood flow. The microscopic specimen clearly shows large foci of calcification (atherocalcinosis), stained dark purple/black. This is the final stage of atherosclerotic plaque formation, characterized by the deposition of calcium salts in necrotic tissue. Around the calcification foci, metachromasia, defragmentation, and depolymerization of elastic fiber bundles are observed, as well as disorganization of the matrix between these bundles. The calcification foci are intensely stained with hematoxylin (blue-violet), and homogenized areas stained with eosin (pink) are visible around them. Significant thickening and destruction of the aortic layers is observed. The atherosclerotic plaque protrudes into the vessel lumen, which, in vivo, leads to hemodynamic compromise.

Pathological features of the classic stages of lipofibromatosis and atherosclerotic ulceration are fully expressed, indicating the development of atherocalcinosis. An example of this is the intense hematoxylin staining of elastic fiber bundles that are not yet fully fragmented, making them resemble calcification foci (normally, elastic fibers do not stain intensely with hematoxylin). Between these two zones, focal proliferation of cells of mesenchymal origin is observed: smooth muscle cells, fibroblasts, fibromyocytes, and macrophages. Connective tissue proliferation and destruction of the elastic framework of the vessel are visible, characteristic of severe stages of atherosclerosis induced by vitamin D2, which accelerates vascular calcification. Administration of vitamin D2 along with cholesterol explains the presence of massive calcifications visible at low magnification.

The microscopic picture (figure) fully confirms the results of laboratory tests from the table.

This image provides visual evidence of the profound organic vascular pathology that developed during the "priming" phase. The effectiveness of treatment (Extract or Rosuvastatin), as demonstrated by biochemical analyses, was aimed at preventing further progression of these lesions and normalizing lipid metabolism to halt the growth of these plaques.

Figure 2. *Aortic arch of rabbits in which atherosclerosis was induced by administering cholesterol powder and vitamin D2 for 3 months and which were then treated for 30 days with the extract composition (Size: 10 × 10. Staining: Hematoxylin-Eosin)*



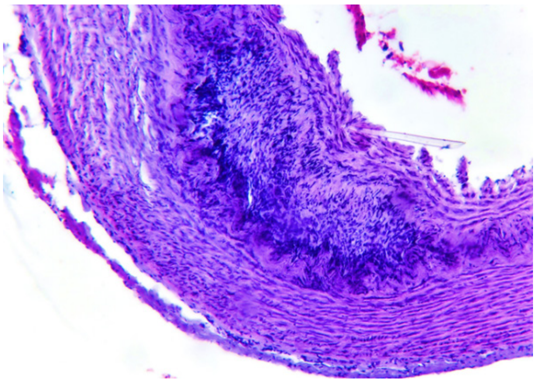
In Group 2, which received treatment with the extract composition for 30 days, Figure 2 demonstrates positive dynamics in aortic structure during therapy.

The ordering of the layers was restored, and the wall appeared more structured. Calcification foci were virtually absent or significantly reduced in volume. A decrease in vacuolization and lipid infiltration of the intima was observed. The improvement in wall structure is explained by a sharp reduction in atherogenic fractions. For example, in the extract group, TC decreased to 2.8±0.2 mmol/L, and LDL to 0.40±0.02 mmol/L, which halted the destructive process and initiated mechanisms for partial tissue restoration.

Group 3: A group of rabbits treated with Rosuvastatin for 30 days.

The surface of the endothelial layer of the aortic tunica intima is uneven, with focal deendothelialized (desquamated) areas. In the subendothelial layer, fibrolipomatous plaque formation is observed due to the proliferation, infiltration, and lysis of foam cells, myocytes, and fibroblasts. Partial focal changes are observed in the aortic media tunica, including disorganization and depolymerization of elastic fibers. Fibrinoid necrosis and plasma edema are found between the media and intima. The adventitia appears normal.

Figure 3. *Aortic arch of rabbits in which atherosclerosis was induced by administration of cholesterol powder and vitamin D2 for 3 months and then treated with rosuvastatin for 30 days (Group 2). General appearance of fibrolipomatous plaque in the subendothelial layer of the tunica intima (Size: 10 × 10. Staining: Hematoxylin-Eosin)*



Conclusion

The study results demonstrated that the experimental model of atherocalcinosis was successfully created and effectively treated. Morphological restoration of the aortic wall is fully consistent with a biochemical reduction in total cholesterol by ~89% in the extract group and normalization of the atherogenic index. Histopathological analysis clearly confirms that severe atherocalcinosis developed during the experiment is significantly corrected by treatment with the extract composition, resulting in stabilization of the vascular wall structure and a reduction in the rate of calcification.

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SYNTHESIS AND DESCRIPTION OF A POLYCARBOXYLATE SUPERPLASTICIZER BASED ON POLYOXYETHYLENE ISOPENTENYL ETHER

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Abstract

This research was conducted to evaluate a new type of polycarboxylate superplasticizer. For the synthesis of a polyarboxylate superplasticizer with high water-lowering capacity, polyoxyethylene ether (TPEG) and acrylic acid (AC) were used as monomers, ammonium persulfate as an initiator, and thioglycolic acid (TGC) as a chain transfer agent. The work discussed the influence of additives on the flowability and shrinkage of the concrete cone. The structure of the water-reducing additive based on carbonic acids was described using infrared spectroscopy. The study also assessed the influence of various series of polyhydroxyethylene ether (TPEG)), the amount of acrylic acid (AA), and ammonium persulfate.

Keywords: *polycarboxylate superplasticizer, carboxyl density, cement paste flowability*

Polycarboxylate superplasticizers are widely used in modern concrete production to increase the flowability of fresh mixtures, as well as to reduce water demand for achieving the specified flowability. It has been demonstrated that they can reduce heat generation during hydration and improve fluidity, which leads to increased strength and durability of hardened concrete products (Witt J., Plank J.). Polycarboxylate superplasticizers are the most promising category of polymer dispersants. From the perspective of chemical structure, these polymers offer numerous advantages: good flowability and spreadability of polycarboxylate superplasticizers in small quantities, wide compatibility with cement, high water reduction efficiency, greater variability of molecular structure, diversity of synthesis technologies, and significant potential for improvement have been studied (Sakai E., Ishida A., Ohta A.; Magarotto K., Torresan I., Zeminian N., 2003; Yamada K., Ogawa S., Hanebara S., 2001). The history of studying and applying polycarboxylate superplasticizers spans only a decade. Research efforts are focused on selecting reactive monomers, determining synthesis temperatures, establishing initiator types, optimizing technological conditions, as well as reducing production costs and controlling product prices (Li S., Yu Q., Wei J., et al., 2011; Lange A. A., Plank J., 2012). Our understanding and knowledge about the structure of polycarbonates, their dispersion properties, rheological characteristics, as well as the relationship between hydration theory and practical applications in construction remain limited (Hirata T., Lange A., Plank J., 2012; Ismailov F. S., 2025). In this study, a number of polycarboxylate superplasticizers were synthesized. Isoamyl alcohol (IPEG) of polyoxyethylene ether and acrylic acid in various quantities were used as monomers, and ammonium persulfate as an initiator and chain carrier. The influence of monomer type, carboxyl group density, initiator quantity, chain-transmitting agent quantity, and pH on the dispersion properties of the superplasticizer was studied by measuring the flowability of the cement paste and the workability of the concrete mix.

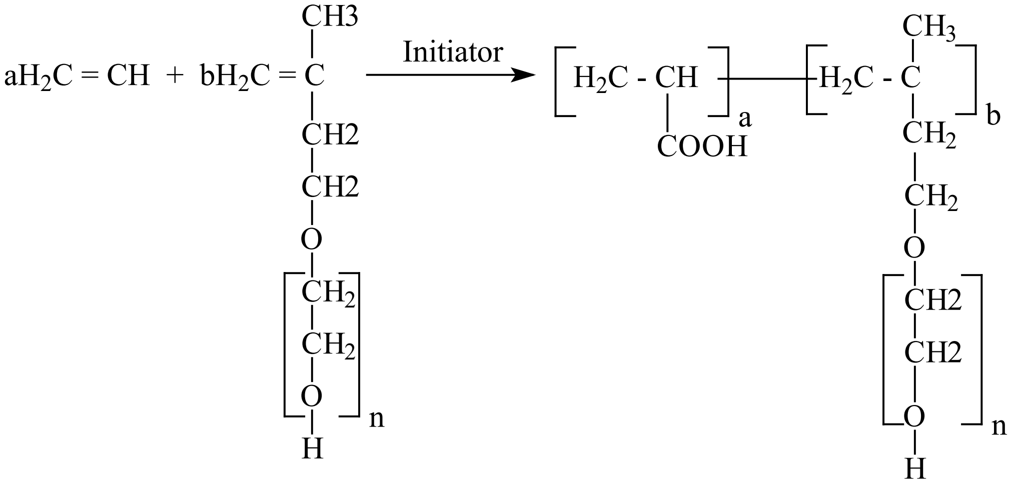
Methodology

When synthesizing a polycarboxylate superplasticizer based on TPEG, 180 liters of distilled water are added to a stainless steel heater reactor. For the first reactor, a solution is prepared by mixing 120 kg of TPEG, 14 kg of acrylic acid, 6 grams of HEA, and mercaptopropionic acid in 180 liters of water, stirring at a rate of 50 rpm until a homogeneous mass is obtained. 180 liters of distilled water is poured into the third reactor, heated to 50 °C, and for 3–4 hours, the contents are pumped from the first reactor to the second using a special chemically resistant pump for 2 hours. The second reactor is constantly heated, stirring at a rate of 100 rpm. The temperature is constantly monitored. Time and temperature play a crucial role in the course of the reaction. After loading the first part of the reagents into the second reactor, 5 liters of hydrogen peroxide solution is introduced through another opening for 40 minutes. After supplying the solution, hydrogen peroxide is maintained at a temperature of 60 °C for 45 minutes. During the synthesis process, a copolymerization reaction of monomers occurs. The amount of dry residue and pH are determined in the resulting product.

Results and analysis

Currently, cement concrete remains the main building material, therefore, the problems of increasing its technological strength and durability remain relevant. Among the additives widely used in the production of concrete and reinforced concrete, plasticizers occupy the first place. The literature analyzes published works on the influence of plasticizing additives on the workability and strength of concrete mixtures, and examines the mechanism of action of plasticizing and superplasticizing additives in cement systems.

Figure 1. *The process of obtaining a semi-carboxylate superplasticizer based on TPEG was carried out according to the following reaction scheme*



The dependence of the TPEG-based polycarboxylate superplasticizer yield on time is presented in Figure 2. As shown in Figure 2, the highest efficiency compared to other ratios is achieved with an HEA, acrylic acid, and TPEG ratio of 3.88:1:1. The synthesis process takes 4 hours. In experiments lasting longer than 4 hours, the superplasticizer yield decreases. This can be explained by the fact that the raw materials exist in various aggregate states for 4 hours or more. The presence of interacting substances in two different aggregate states reduces their interaction.

Table 1. *Amount of substances for the synthesis of the superplasticizer half-carboxylate based on TPEG*

No.	Substances used in synthesis	Quantity (kg)
	1 part solution	
1.	TPEG	120
2.	water	360
3.	acrylic acid	14
4.	HEA	6
5.	MPA-3. 95%	0.5
	2 part solution	
6.	water	5
7.	APS, 99%	0.5

Figure 2. *Time dependence of the yield of a polycarboxylate superplasticizer based on TPEG*

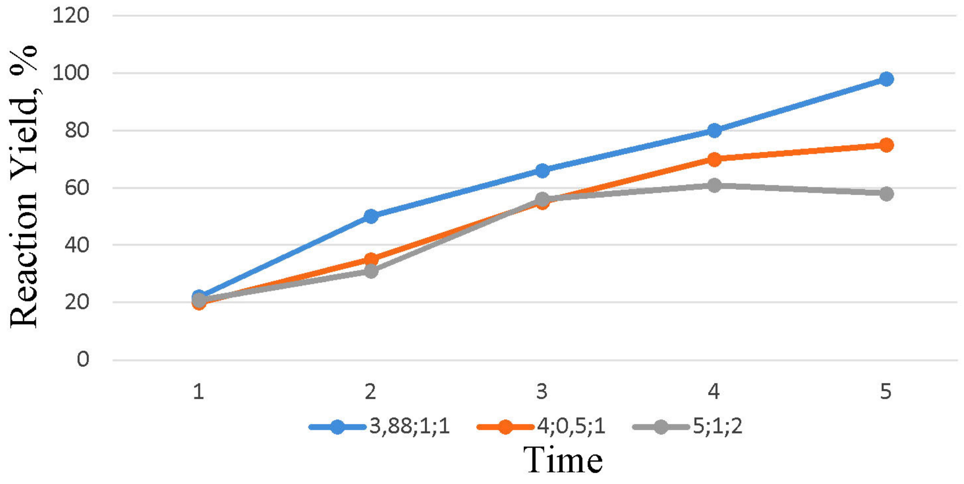


Figure 3. *Dependence of the yield of TPEG-based polycarboxylate superplasticizer on the molar ratio*

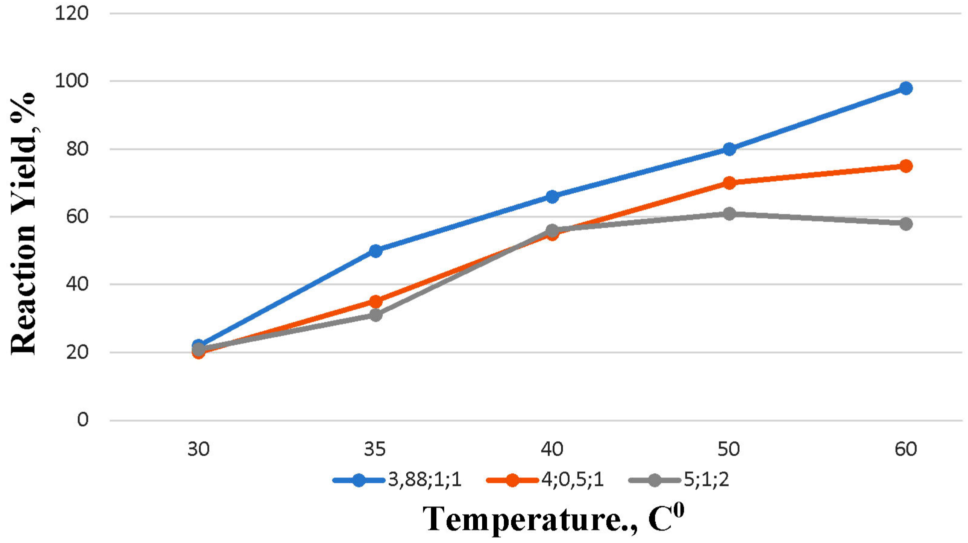


Figure 3. Dependence of the yield of a polycarboxylate superplasticizer obtained on the basis of TPEG on the molar ratios of acrylic acid, HEA, and TPEG As can be seen from Figure 3, the optimal ratio of components in the production of a polycarboxylate superplasticizer is 3.88:1:1, under these conditions, the profitability of the superplasticizer is 90%. The highest dry residue is obtained at a ratio of the initial products of 4:0.5:1 and 5:1:2, but the plasticizing effect of the obtained superplasticizers is low. Based on this, the optimal temperature of 60 ˚C was chosen for obtaining superplasticizer. Reaction time also plays an important role in the production of superplasticizers. To choose the optimal reaction yield temperature, all three initial product ratios were selected. The following figure shows the dependence of superplasticizer yield on reaction time at a temperature of 60 ˚C. As can be seen from the figure, as a result of carrying out the reaction under optimal conditions for 5 hours, a superplasticizer yield of 90% is obtained. Under such conditions, further continuation of the reaction leads to a decrease in yield. This is due to the intensification of parallel reactions (for example, binding, decomposition, intermolecular interaction), which leads to a decrease in the plasticizing effect of superplasticizing additives.

Table 2.

No.	Mole ratios	Time	Reaction Yield, %	No.	Mole ratios	Time	Reaction Yield, %
1.	5:1,5:1,5	2	26.2	11	5:1,5:1,5	4	49.4
2.	5:2:2,5		37.3	12	5:2:2,5		65.8
3.	4:0,5:1		47.4	13	4:0,5:1		72.5
4.	5:1:2		54.3	14	5:1:2		78.7
5.	3,88:1:1		56.5	15	3,88:1:1		**79.8**
6.	5:1,5:1,5	3	35.5	16	5:1,5:1,5	**5**	49.5
7.	5:2:2,5		60.5	17	5:2:2,5		65.9
8.	4:0,5:1		70.5	18	4:0,5:1		72.6
9.	5:1:2		72.4	19	5:1:2		78.7
10.	3,88:1:1		75.5	20	**3,88:1:1**		90

Figure 4. *IR spectrum of a polycarboxylate superplasticizer based on TPEG*

PerkinElmer Spectrum IR Версия 10.7.2
22 октября 2025 г. 12:45

Аналитик Analyst
Дата Время 22 октября 2025 г. 12:45

Имя образца	Описание	Длина оптического пути (мм)
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Table 2. presents the influence of various factors on the superplasticizer yield based on the presented results: time and molar ratios of the initial substances. As can be seen from Figure 2, compared to others, acrylic acid and NEA are obtained at the highest TPEG ratio of 3.88:1:1, however, the resulting product contains derivatives of di-naphthylsulfones. Therefore, when studying the plasticizing effect of mono-, di-, and other polyhydric alcohols, their derivatives are of particular importance. From the obtained results, it can be seen that at a molar ratio of acrylic acid and HEA, TPEG 3.88:1:1, and a process duration of 5 hours, the yield of the polycarboxylate superplasticizer was the highest.

Figure 4 shows that the broad peaks from 2500 sm^{-1} to 3000 sm^{-1} are attributed to the stretching vibrations of the O-H group. The peaks at 1731 sm^{-1} and 1466 sm $^{-1}$ exhibit characteristic absorption zones of the polyethylene oxide group (CH2CH2O). A typical absorption peak of stretching vibrations of the C-O-C structure was observed at 1060 sm$^{-1.}$ The characteristic absorption peak of the COO-group appeared at 1466 sm^{-1}. The absence of resonance for the carbonyl bond in AA and TPEG accounts for the observed shift towards higher wavenumbers. Thus, the vibrational signals observed in the IR spectra confirm the successful synthesis of the polycarboxylate superplasticizer.

Conclusion

The results of the conducted research showed that concrete with the addition of superplasticizer is characterized by high strength and durability under conditions of reduced water consumption. Today, increasing attention is being paid to concrete and concrete products with the addition of superplasticizers. Using macromonomers and monomers, it is possible to synthesize a high-performance polycarboxylate superplasticizer and provide a new superplasticizer. By analyzing various factors influencing the effectiveness of polycarboxylates, optimal conditions for the synthesis process of a new type of polycarboxylate superplasticizer with high dispersity were determined. Factors influencing the reaction include acid ratio, initiator concentration, pH level, and additives. There is an opportunity to introduce this method into industrial production.

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NEW ANTI-CORROSION SOLUTIONS AND PROTECTION OF STEEL EQUIPMENT IN THE OIL AND GAS INDUSTRY AGAINST POLYTHIONIC ACID CORROSION

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Abstract

The article examines the types of new anti-corrosion solutions as a detergent for cleaning heat exchangers, evaporators and condensers from the surface of oil and gas industry facilities and the process of corrosion development with polythionic acid, as well as its effect on various stages in the oil refining process. Attention is paid to the susceptibility of nickel-based stainless steels to corrosion by polythionic acid and a modern approach to this problem is presented.

Keywords: *hydrochloric acid, hydrofluoric acid, thionic acid, desulfurization, hydrosulfuration*

Raw steel is the most widely used type of metal in the world due to its lack of complex structure and low cost as an acceptable material in modern manufacturing plants. At the same time, interest in its use is limited due to low corrosion resistance, especially in acidic and alkaline environments. The use of corrosion inhibitors is being studied by various researchers as a means of reducing the rate of corrosion and thereby reducing losses in large industrial plants and equipment. Today, inhibitors from Russian and German manufacturers are mainly imported into our republic, and the demand for them is high in water supply networks, the chemical, petrochemical, and gas industries, especially in electrochemistry.

Corrosion inhibitors usually absorb onto the metal surface and form a protective film.

Research into corrosion protection methods is mainly carried out in the following areas:

– impact on metal;
– impact on the environment;
– development of combined and complex methods of protection.

This article examines a solution consisting of a mixture of hydrochloric acid, hydrofluoric acid, chelating agents, surfactants, copper complex and acridine. The solution is effective for cleaning equipment without causing corrosion. Orange inhibitor blocks anodic and cathodic areas on steel surfaces of process equipment.

Equipment used in power plants, chemical and petrochemical plants, pipelines, air conditioning units in oil refineries, and many other industrial environments are susceptible to corrosion due to exposure to chemicals released from industrial processes. Precipitated solids reduce heat transfer efficiency and often cause pipes to fail due to overheating, resulting in clogged or dirty equipment. Waterborne deposits are usually inorganic in nature, especially in hot and closed systems such as steam generators or heat exchangers. Common deposits found include sulfides, alkaline earth carbonates, sulfates and silicates.

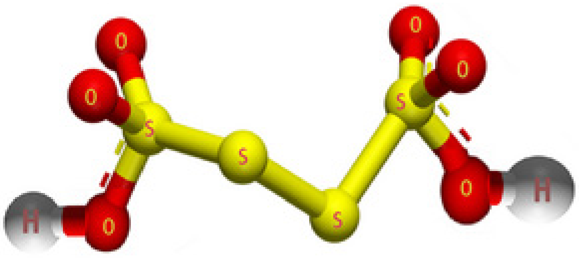
Polythionic acids are unstable and are known only in aqueous solutions. Salts of polythionic acids – polythionates – are more stable; some of them are obtained in the form of crystals. Hydrochloric acid is widely used for chemical cleaning of structural steels used in heat transfer and piping systems and produces soluble products that serve to dissolve calcium or magnesium carbonates. However, hydrochloric acid does not dissolve sulfates and silicates. Therefore, other chemicals must be mixed or added with hydrochloric acid. It is also well known that hydrochloric acid is very corrosive.

In addition, if copper salts are present in the environment, they dissolve and precipitate on iron surfaces, leading to severe local corrosion.

The purpose of this invention is to provide a non-toxic industrial cleaning composition effective for removing oxides from the surface of equipment used in various industries.

Thionic acids are characterized by sulfonic acid groups ($–SO_2OH$), which are linked directly or through sulfur atoms. The sulfur atoms in thionic acid compounds are bonded only to another S, which distinguishes them from other sulfur-containing compounds. As a special type of thionic acid, polythionic acid has a unique molecular structure characterized by many sulfur atoms.

Picture 1. *General structural formula of the thione*



In the process of gradual hydrolytic decomposition, thiosulfuric acid is thus partially converted into polythionic acids of a higher degree of sulfurization, hexathionic and, possibly, other higher polythionic acids. In the solution, along with tetrathionic acid, pentathionic and hexathionic acids were present, and in some cases higher degrees of sulfurization were revealed, since the thiosulfuric acid in the solution was partially consumed for the sulfurization of the already formed pentathionic acid. We have recently been able to prove that octathionic acid is present in the solutions obtained as a result of this reaction. But its amount in such solutions is very small; the sulfurization of hexathionic acid, i.e., the interaction of sulfur atoms in the process of increasing the length of polymer chains, occurs in a non-directional manner.

The production of a polythionic acid can be influenced by several factors, including (a) the type, concentration, and purity of sulfur-containing compounds used in the synthesis of the polythionic acid, and (b) reaction conditions such as temperature, pH, and reaction time. Sulfur-containing compounds play a decisive role in the production of polythionic acids, since they can affect the properties, reactivity and quality of the final product. The various sulfur-containing compounds used in the production of polythionic acids can significantly affect the quality of the resulting polymer, including its concentration, stability and corrosivity. For example, H_2S is a highly reactive and corrosive compound that readily reacts with oxygen and water to form a highly reactive and corrosive acid solution. Polythionic acid can also be synthesized using SO_2. However, due to the lower corrosive activity of SO_2 compared to H_2S, the resulting solutions of polythionic acid exhibit low reactivity. In addition, the initial ratio of SO_2 and H_2S can significantly affect the nature of the reaction products. When the environment is saturated with H_2S, the reaction produces elemental sulfur and short-chain polythionates, primarily S_4O_2-6.

On the other hand, when SO_2 is the main reactant, the longer chain polythionates from × 4 to 8 are mainly formed. Strong oxidizing agents such as hydrogen peroxide or elemental chlorine convert polythionates into sulfate ions (SO_2 –4). This is consistent with the fact that polythionates can degrade rapidly in the presence of small anions due to the cleavage of internal S–S bonds.

Polythionic acid can be synthesized by reacting H_2S and sulfur dioxide (SO_2) in an aqueous solution. This reaction occurs under normal conditions, including ambient pressure, temperature and a pH range of 3 to 2. When H_2S oxidizes in the liquid phase, it forms polythionate ions (S_xO_2-6). The ratio of H_2S and SO_2 in the reactants has a strong influence on the type and distribution of products formed. With an excess of H_2S, short-chain polythionates are predominantly formed, mainly S_4O_2-6. Conversely, when SO_2 is the dominant reactant, the main products are longer chain polythionates with x values between 4 and 8. The pH value of the reaction medium also plays an important role. Higher pH values lead to the formation of shorter polythionates and finally, at pH>8, thiosulfate (S_2O_2-3) is formed:

$$(2_x-5)\ H_2 + (x+5)\ SO_2 \rightarrow$$
$$3S_xO_6^{2-} + 6H^+ + (2_x-8)\ H_2O$$

Types of polythionic acids:

$H_2S_3O_6$ – Triton
$H_2S_4O_6$ – Tetraton
$H_2S_5O_6$ – Pentaton
$H_2S_6O_6$ – Hexatone

Polythionic acid is stable only in aqueous solutions and decomposes rapidly at high concentrations, releasing the elements S, SO_2 and sometimes sulfuric acid (H_2SO_4). Polythionate ions are significantly more stable than the corresponding acids; the most stable is polythionic acid, which contains less S in the chain ($x = 3, 4, 5, 6$). Among them, the least stable is $H_2S_3O_6$ – (triton). The free acid form of polythionic acid dissolves slowly in aqueous solutions, even at room temperature, forming S and sulfates (SO_2-4) as end products. Free acid exists only in the form of an aqueous solution without color or odor. In contrast, $H_2S_4O_6$ is the most stable of the polythionic acids, exhibiting properties similar to $H_2S_2O_6$ in terms of heat of dilute sodium hydroxide neutralization and electrical conductivity. The acids $H_2S_5O_6$ and $H_2S_6O_6$ are relatively stable in acidic solutions, but decompose in almost neutral or alkaline solutions to form elemental S and lower polythionates (S_4O_2-6 for pentathionic acid and S_5O_2-6 for $H_2S_6O_6$).

Temperature is critical in the synthesis of polythions and affects the reaction rate and product stability. To ensure efficient conversion of starting materials into polythionic acids, the temperature must be carefully controlled, typically within an appropriate range of 20 °C to 30 °C. At the same time, the thermal instability of the compound at extremely high temperatures (e.g. H_2S SO_2) causes the molecular bonds in the polythionic acid to become increasingly unstable and weak, leading to destruction of the chemical structure and consequent thermal degradation of the product. Reaction time significantly affects the synthesis of polythionates. Typically, longer reaction times provide sufficient time for the sulfur-containing compounds to be completely converted to polythionate. Adequate reaction time minimizes the presence of unreacted compounds and other impurities. This also helps prevent side effects or product failure.

In the refinery, polythionic acid formation is typically observed in corrosive environments with sulfur-containing compounds such as H_2S and SO_2, especially O_2 and H2O, at high temperature and low pH. Installations such as distillation columns, amine systems and sour water treatment plants are very susceptible to polythionic acid formation due to high concentrations of sulfur compounds. Desulfurization processes used in petroleum refineries, including oxidative-extractive desulfurization (ODS), oxidative desulfurization, hydrodesulfurization, adsorption desulfurization, and biodesulfurization, also contribute to the formation of polythionates as sulfur compounds.

Inflate, rotate and change during these processes.

In refineries, polythionic acid corrosion occurs in environments containing sulfur-containing compounds such as H_2S and SO_2. Corrosion by polythionic acid occurs in several stages, including the formation of acid and polythionates, attack of metal surfaces, and acceleration of corrosion. During processing, sulfur-containing compounds react with H_2O, entering into a series of chemical reactions and forming H_2SO_4. It is then oxidized to form polythionic acid. Under the influence of oxidizing agents, polythionic acid is oxidized and converted into polythionate ions, such as SO_2-4, which are soluble in water and can be mobile in the oil refining environment.

The presence of this acid can cause localized corrosion of metal surfaces due to the action of oxide layers on metal surfaces. When carbon steel is exposed to S_xO_2-6, it is immediately exposed and releases hydrogen gas and forms Fe_2^+. These iron ions react with polythionates to form a protective layer of ferrous sulfate (Fe_2SO_4) on the metal surface. This can be seen in equations 2 and 4. This protective layer acts as a barrier and protects the metal from key attacks. Thus, the longevity of carbon steel tanks and pipes depends on maintaining the protective Fe_2SO_4 layer. In cases where, along with metal corrosion, a protective layer of corrosion products is formed, the rate of corrosion is determined by the slowest stage: diffusion of the oxidizer through a layer of corrosion products (Fe_2SO_4 for carbon steel), the corrosion rate is the reaction of the corrosion itself or the corrosion products away from the metal surface and the rate of diffusion into the surrounding solution.

The rate of corrosion is ultimately determined by the slowest of these stages.

$$2O_2 + 2H_2O + S_3O_6^{2-} \rightarrow$$
$$SO_4^{2-} + 2H_2SO_4$$
$$2S_4O_6^{2-} + 6H_2O + 7O_2 \rightarrow$$
$$2SO_4^{2-} + 6H_2SO_4H_2SO_4 + Fe \rightarrow FeSO_4 + H2$$

The standard method of protecting sensitive stainless steel involves preventing or neutralizing the formation of corrosion with polythionic acid. To neutralize the rot, it is recommended to wash the equipment with a weak solution of soda (1–5%) before leaving it for air.

Equipment must be soaked for a minimum of 2 hours to ensure effective neutralization. Simply treating equipment with a baking soda solution is not sufficient to prevent polythione formation. If sediment or sediment is present, the solution should be stirred vigorously by shaking for at least 2 hours. To neutralize acids, it is necessary to take into account the formation of a Na_2CO_3 film, which can additionally neutralize acids using a soda solution. Before washing with soda water, it is recommended to evaluate the effect of alkaline substances on the catalysts. It is necessary to fill the equipment with a soda solution and re-treat the surfaces with a residual soda film.

All surfaces of the equipment should be thoroughly moistened with a soda solution and rinsed with water before washing with alkali. If sulfur-containing fuel was used to fire the stove, the outer part of the stove pipes should be thoroughly washed with a soda solution to reduce the risk of corrosion by polythionic acid. Any remaining caustic wash solutions should be drained to prevent corrosion due to evaporation of carbonates and chlorides. Dryers and humidifiers should be used to prevent the formation of liquid water. These methods are designed to prevent water vapor condensation and maintain an alkaline environment by adding ammonia (NH_3) or Na_2CO_3, which provides improved protection against polythionic acid attack. These solutions provide the basis for eliminating corrosion caused by polythionic acids in refineries. The study examines the basic properties of polythionic acid, the mechanism of corrosion, its prevention and protection methods.

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GC–MS ANALYSIS OF BIOACTIVE COMPOUNDS FROM PLEUROTUS OSTREATUS

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Abstract

In this study, the ethyl acetate extract of Pleurotus ostreatus mushroom was analyzed using gas chromatography–mass spectrometry (GC–MS, EI ionization). The main objective of the study was to identify lipophilic secondary metabolites in the mushroom and evaluate their structural properties. According to the results of GC–MS analysis, three main bioactive components were identified in the extract – ethyl linoleate, ergosta-3,5,7,22-tetraene (22E) and ergosta-5,7,22-trien-3-ol acetate, and their molecular ions and fragmentation patterns were confirmed to match the database. Ethyl linoleate was characterized by the McLafferty rearrangement characteristic of fatty acid ethyl esters, while sterol derivatives were identified by fragment ions characteristic of the ergosterol skeleton. The results obtained show that the ethyl acetate fraction of P. ostreatus is rich in bioactive sterols and fatty acid esters, allowing this mushroom to be evaluated as a promising raw material for the development of pharmaceutical, nutraceutical, and functional food products.

Keywords: *Pleurotus ostreatus, GC–MS, ethyl linoleate, ergosterol derivatives, secondary metabolites*

Introduction

In recent years, the Pleurotus ostreatus mushroom has been widely studied as a natural resource with high nutritional and pharmacological value. While its primary metabolites (amino acids, vitamins, lipids, and carbohydrates) enhance its nutritional value, secondary metabolites (phenolic compounds, terpenoids, flavonoids, and polysaccharides) determine the pharmacological properties of the mushroom, including antioxidant, antibacterial, and antifungal activities (Zhang et al., 2020; Patel et al., 2019). Recently isolated terpenoid compounds, such as pleurotusin A and pleurotusin B, have been shown to have potent antioxidant and antibacterial properties (Singh et al., 2022). Metabolism studies have shown that genes in P. ostreatus cells are associated with regulators responsible for polysaccharide synthesis and cellulose degradation (Chen et al., 2022). In addition, salicylic acid activates stress response mechanisms and stimulates the synthesis of antibiotics, polyketones, and other bioactive substances (Kumar et al., 2021). Heat stress also significantly alters fungal metabolism.

Studies have shown that heat stress increases the content of amino acids, lipids, vitamins, and carbohydrates in the mycelium, and also stimulates the synthesis of metabolites associated with stress tolerance (Wang & Zhang, 2021). At the same time, heat leads to an increase in the amount of more than 130 metabolites in mushrooms, including substances that stimulate the growth of beneficial microorganisms such as Trichoderma asperellum (Patel et al., 2020). The co-cultivation approach is also an effective strategy for enhancing the production of metabolites. As a result of co-culturing P. ostreatus and Trametes robiniophila, silenced genes are activated and new sesterterpenes are synthesized, which show strong activity against pathogenic fungi (Li et al., 2023). This approach is promising for the development of new drugs and the identification of bioactive compounds. HPLC and mass spectrometry methods have created the possibility of comprehensive qualitative and quantitative analysis of P. ostreatus metabolites. The use of different solvents allows for the simultaneous detection of metabolites and the assessment of their pharmacological and nutraceutical properties (Zhou et al., 2020; Chen et al., 2022). At the same time, salicylic acid, as a signaling molecule, activates genes, stimulates the biosynthesis of secondary metabolites, and increases the stress resistance of the fungus (Kumar et al., 2021). As a result, the data presented in the literature scientifically substantiate the biological activity, metabolite synthesis, and stress adaptation mechanisms of the Pleurotus ostreatus mushroom, and also indicate the prospects for their application in the fields of cosmetology, pharmaceuticals, and nutraceuticals.

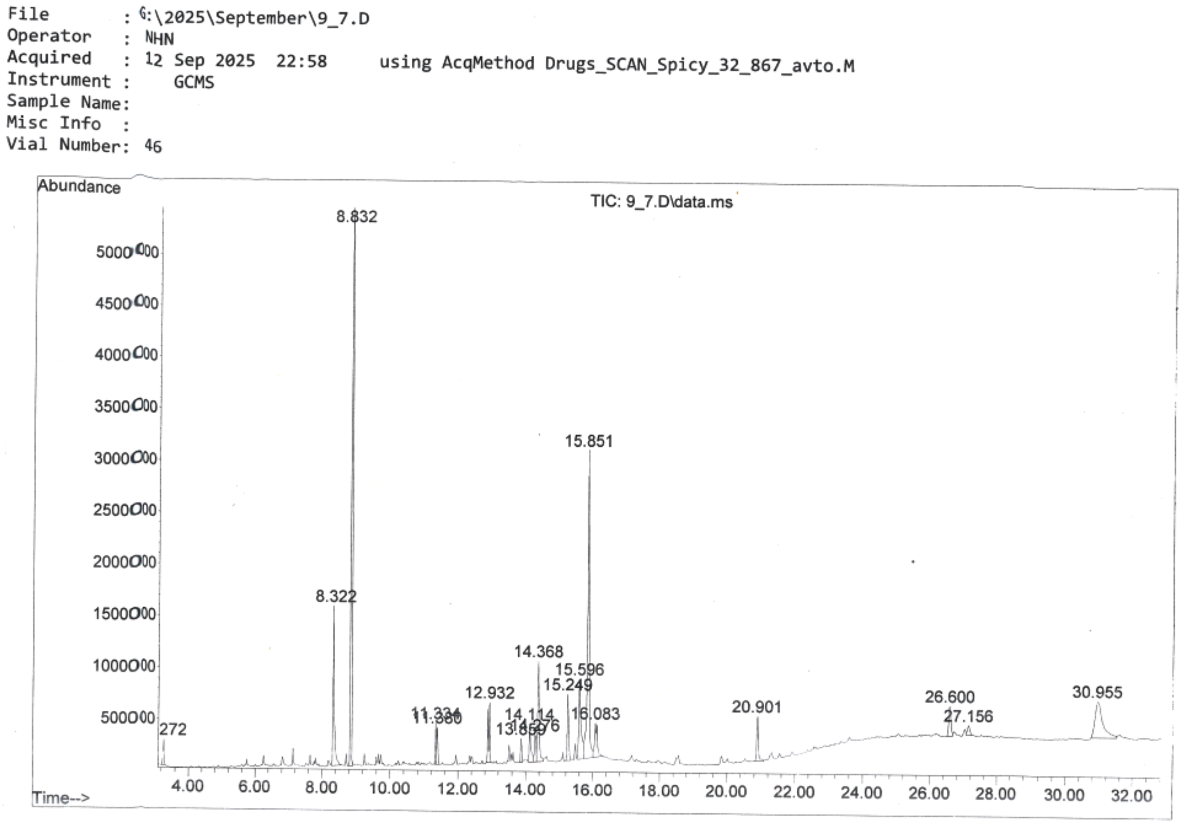
Sample preparation

Pleurotus ostreatus was grown and harvested in the field of the Department of Microbiology of the State University of Antioch for 15 days. The resulting crop was dried and extracted with ethyl acetate.

Results and Discussion

The ethyl acetate fraction of Pleurotus ostreatus was analyzed by GC–MS (EI, 70 eV) and the extract was found to contain secondary metabolites of mainly lipophilic nature.

Figure 1. *GC–MS/EI–MS analysis of P. ostreatus sample (solvent ethyl acetate)*



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File       : G:\2025\September\9_7.D
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Acquired   : 12 Sep 2025   22:58      using AcqMethod Drugs_SCAN_Spicy_32_867_avto.M
Instrument :    GCMS
Sample Name:
Misc Info  :
Vial Number: 46
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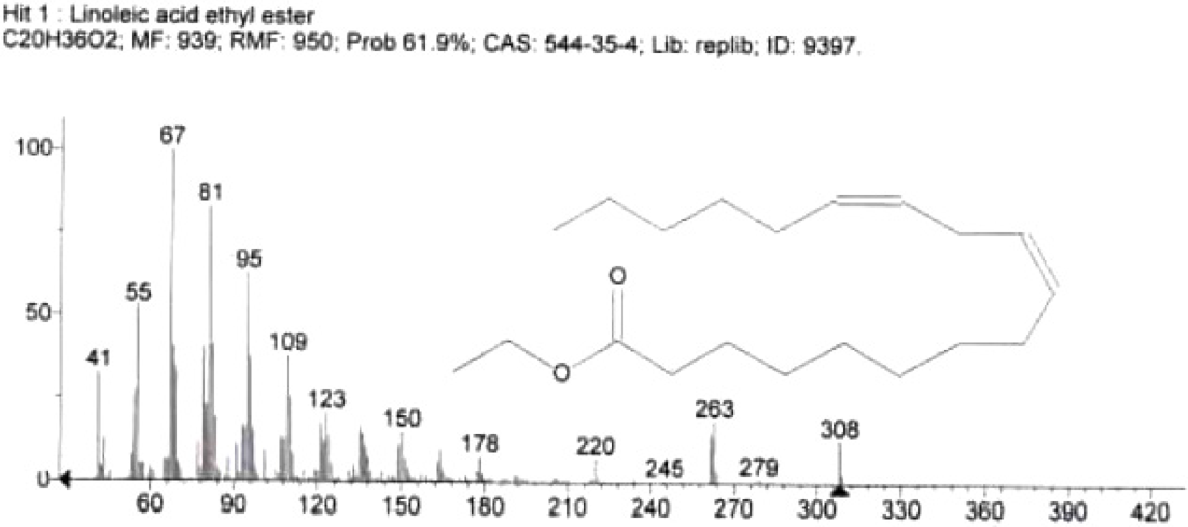
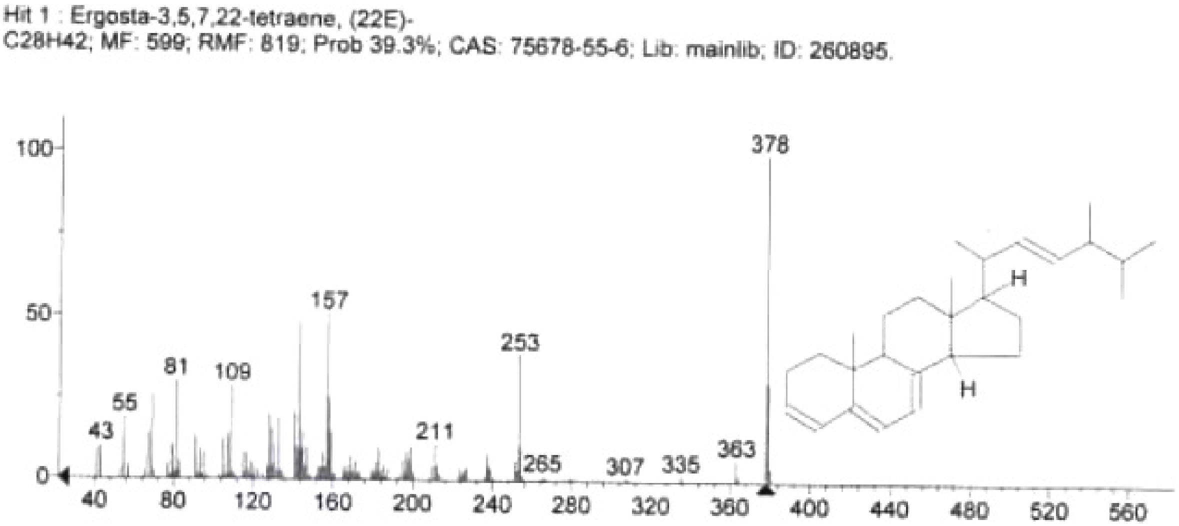
Intense peaks were observed in the chromatogram between 18.5–24.1 minutes, which were confirmed by spectral analysis to be related to ethyl esters of fatty acids and sterol derivatives. The molecular ion of ethyl linoleate was observed at m/z 308 with low intensity, which is typical of fatty acid esters and is explained by the easy cleavage of the carbon chain. The basic peak observed at m/z 87 in the spectrum was formed as a result of McLafferty rearrangement and reliably confirms the presence of an ester functional group. Also, the fragment ions at m/z 55, 81 and 95 correspond to allyl and dienyl cations associated with double bonds in the linoleate chain. These results indicate the presence of ethyl linoleate in the P. ostreatus extract and its possible biological role in lipid metabolism.Sterol fraction analysis revealed a molecular ion of m/z 378 for ergosta-3,5,7,22-tetraene, and a sequential fragmentation characteristic of the sterol nucleus (m/z 109, 157, 211, 253, and 335). These fragments are characteristic of the ergosterol skeleton and are consistent with the data reported in the literature. Although a relatively low match (7.62%) with the database was recorded for ergosta-5,7,22-trien-3-ol acetate, the characteristic distribution of fragment ions indicates the presence of an acetated sterol. This is explained by the partial decomposition of sterol derivatives during the extraction process or the separation of the acetate group during ionization.

Figure 2. *Linoleic acid ethyl ester*



Hit 1 : Linoleic acid ethyl ester
C20H36O2; MF: 939; RMF: 950; Prob 61.9%; CAS: 544-35-4; Lib: replib; ID: 9397.

Figure 3. *Ergosta-3,5,7,22-tetraene*



Hit 1 : Ergosta-3,5,7,22-tetraene, (22E)-
C28H42; MF: 599; RMF: 819; Prob 39.3%; CAS: 75678-55-6; Lib: mainlib; ID: 260895.

The results obtained are consistent with the data on secondary metabolites of P. ostreatus presented in the literature and confirm that this fungus is an important source of lipophilic bioactive compounds, in particular sterols and fatty acid esters. The ethyl acetate solvent has a medium polarity and allowed for the efficient extraction of metabolites of sterol and lipid nature.

An extract from the ethyl acetate fraction of Pleurotus ostreatus was analyzed by GC–MS and three major bioactive metabolites were identified: ethyl linoleate, Ergosta-3,5,7,22-tetraene (22E), and Ergosta-5,7,22-trien-3-ol acetate.

Figure 4. *Ergosta-5,7,22-trien-3-ol acetate*

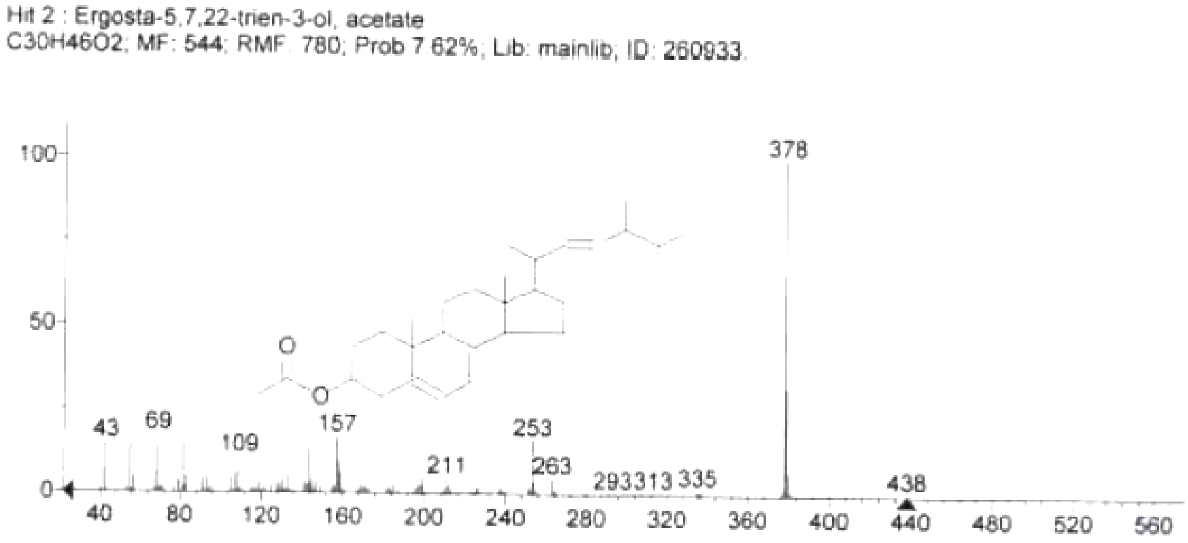


Table 1.

Metabolite	Chemical formula	Molecular mass (Da)	RT (min)	Molecular ion (m/z)
Ethyl linoleate	$C_{20}H_{36}O_2$	308	18.5	308
Ergosta-3,5,7,22-tetraen	$C_{28}H_{42}$	378	23.2	378
Ergosta-5,7,22-trien-3-ol acetate	$C_{30}H_{46}O_2$	378	24.1	378

Conclusion

In this study, the ethyl acetate extract of Pleurotus ostreatus mushroom was analyzed for the first time in a comprehensive manner using the GC–MS method. As a result of the analysis, the extract contained ethyl linoleate and two bioactive sterol derivatives belonging to the ergosterol skeleton – ergosta-3,5,7,22-tetraene and ergosta-5,7,22-trien-3-ol acetate. The spectral fragmentation patterns reliably confirmed the structural properties of the identified compounds. The obtained data indicate that P. ostreatus is rich in lipophilic secondary metabolites, scientifically justifying its prospects for the production of pharmacological, nutraceutical and functional food products. In the future, it is advisable to conduct quantitative analysis of these metabolites, evaluate their biological activity, and study their biosynthesis under the influence of stress factors.

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SORPTION PROPERTIES OF SORBENTS THAT PURIFY SUNFLOWER OIL

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Abstract

Today, the variety of materials with sorption properties is expanding. Similarly, activation methods are also becoming more diverse. Among materials with sorption properties, clay minerals are some of the most effective, inexpensive, and environmentally safe options. It is important to note that obtaining sorbents with selective and desorption properties is one of the most pressing issues of our time. Research on obtaining sorbents for the purification of sunflower oil has been limited. However, at the same time, the consumption of sunflower oil is increasing, and along with it, various diseases are emerging. This article presents experiments on the production and application of selective sorbents. A comparative analysis of the resulting sorbents is also provided.

Keywords: *Bentonite clay, sorption capacity, activation, aromatic fiber, silicon, activated carbon, filtration*

The urgency of the issue

Sunflower oil is widely used in industrial and food applications, but significant contamination occurs during its production and processing. These contaminants can cause environmental damage, making it necessary to develop effective purification methods. Bentonite clays, along with their activation techniques, are of high importance in this purification process. This article examines the role of bentonite clays in refining sunflower oil, their activation methods, and their overall effectiveness. The objective is to analyze the use of bentonite as a sorbent and evaluate its efficiency in the refining process.

Currently, numerous scientific studies are being conducted to improve the use of bentonite as a sorbent. The majority of these are aimed at refining the methods for its physical and chemical activation. In this article, we will review the latest scientific works and innovations.

Sunflower oil is a material widely used in industrial and food applications due to its properties. It is rich in fatty acids and lipids, and also contains high levels of polyphenols. However, sunflower oil can oxidize quickly and lose its quality during long-term storage. These processes lead to the formation of impurities, which must be effectively removed. Bentonite clays, with their high sorption capacity and chemical neutrality, play a crucial role in this process.

The contamination of sunflower oil harms the environment. Polluted oils contaminate water resources and negatively affect terrestrial flora and fauna. Sorbent materials used in the purification process, particularly bentonite, help to reduce this contamination.

Bentonite is a natural clay mineral primarily composed of montmorillonite, illite, kaolinite, and other minerals. It is highly hygroscopic and exhibits excellent surfactant and sorption properties. The sorption characteristics of bentonite are attributed to the voids and chemical groups present in its porous surface structure.

Experimental section

The effectiveness of bentonite clays is increased through chemical activation methods. The activation methods are as follows:

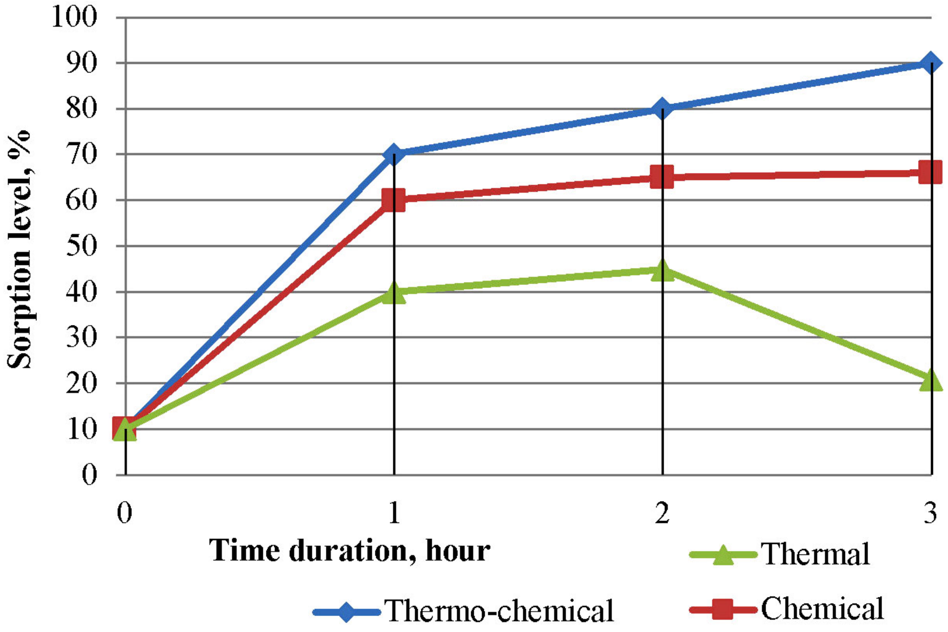
Thermo-chemical activation: Acids (sulfuric acid, nitric acid, hydrochloric acid, phosphoric acids) or bases (hydroxides of alkali and alkaline earth metals) are added to the bentonite and heated in the range of 200–250 °C. This activates its surface and increases its sorption capacity.

Chemical Activation: Acids or bases are added to bentonite, which activates its surface and increases its sorption capacity.

Thermal Activation: Bentonite is heated to a high temperature (400–600 °C), modifying its structure and enhancing its absorption capacity.

The effect of activation methods on the oil purification efficiency of bentonite clays is shown in the diagram in Figure 1.

Figure 1. *The effect of activation methods on the sorption properties of bentonite*



Bentonite, through its activation methods, works effectively in the purification of sunflower oils. It possesses the ability to absorb substances that are harmful to living organisms, contaminate the oil, and reduce its shelf life, which ensures the output of a purified oil.

Bentonite clays are used to refine sunflower oil. This process concludes with the removal of excess substances after the sorbent material is used, followed by the reprocessing of the refined oil. The sorption properties of bentonite make it a highly effective material.

Bentonite clays are inexpensive, natural, and environmentally safe. They possess a high absorption capacity and are effective in purifying many chemical compounds. However, bentonite is difficult to process, and sometimes additional external factors or activating agents are required for chemical activation. Furthermore, some types of bentonite have poor water solubility, which reduces processing efficiency.

Table showing the effectiveness of bentonite clays and other sorbent materials in refining sunflower oil.

Table 1.

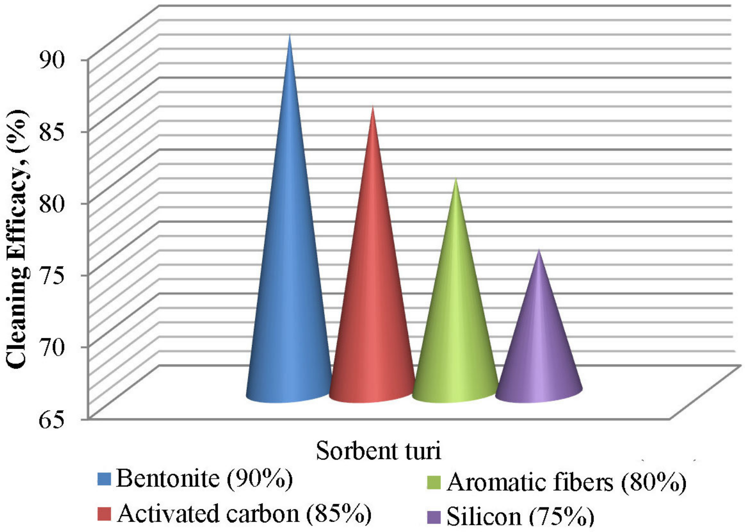
Type of sorbent	Cleaning efficiency (%)	Ecological security	Price range
Bentonite	90%	High	Middle
Activated carbon	85%	Middle	High
Silicon	75%	High	Middle
Aromatic fibers	80%	Low	Low

The data in Table 1 indicates that bentonite effectively purifies oil, is an environmentally friendly material that does not harm the environment, and is moderately priced compared to other sorbents.

Several companies worldwide have developed technologies for refining sunflower oil using bentonite clays. For instance, BASF successfully utilizes bentonite clays for the purification of oily liquids.

When selecting bentonite, its adsorption capacity, mechanical strength, chemical stability, and environmental safety are important. Furthermore, the solubility of bentonite in liquid, as well as its potential for recycling, are also taken into account during the selection process.

Figure 2. *Stages of the sunflower oil refining process*



A diagram illustrating the sunflower oil purification process and the role of sorbents at each stage.

1. Oil Collection → 2. Impurity Identification → 3. Sorbent Application → 4. Filtration → 5. Purified Oil

1. Oil Collection: Sunflower oil is collected.

2. Impurity Identification: Impurities (chemical or mechanical) in the oil are identified.

3. Sorbent Application: Bentonite or another sorbent is added.

4. Filtration: Impurities are absorbed by the sorbent.

5. Purified Oil: The oil, now free of impurities, is separated.

Bentonite materials are considered affordable and effective. Their cost is directly related to their absorption properties. The processing and activation of bentonite should also be economically viable. The reusability of bentonite is an important aspect. Specifically, after the oil is purified, the desorption properties of the sorbent are utilized. The purified oils can be reprocessed and used as new products. The reprocessing of bentonite ensures its environmental safety. As a result, this facilitates the development of waste-free technologies and prevents the release of environmental pollutants.

Bentonite clays are significant from an environmental safety perspective, as they are natural and biodegradable.

Bentonite clays are considered environmentally friendly materials, and their negative impact on the environment is minimal. They decompose naturally and do not release harmful substances into the environment.

The effectiveness of bentonite clays can be enhanced through the use of nanotechnologies, biosorbents, and other advanced materials. These materials possess high sorption capacities, which further improve the purification process. It is possible to develop new approaches for bentonite activation methods, for instance, by utilizing nanotechnologies. This increases the efficiency of bentonite and expands its range of applications.

Bentonite clays are an effective and ecologically safe material for refining sunflower oil, and their activation methods contribute to improving the technological process. In the future, it is anticipated that bentonite clays will be further developed with the aid of new materials and technologies.

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PURIFICATION OF PHENOL SOLUTION USING MODIFIED MONTMORILLONITE

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Abstract

There is growing interest in the modification of clays to organic materials, i. e. organoclays, in which metal cations on the surface of minerals are removed by exchange with organic cations. Organic cations can also enter into ion exchange reactions with cations that are exchanged between layers. The clay surface can be modified to become strongly organophilic. Phenolic hydrocarbons, including p-nitrophenol and p-chlorophenol, are widely used in pharmaceutical, petrochemical and other chemical manufacturing processes. Due to the potential harm of phenolic compounds to human health and the environment, wastes containing phenolic compounds must be treated before being discharged into receiving water bodies. Secondary biological treatment processes are commonly used to treat domestic and industrial wastes, but cannot successfully remove high concentrations of phenolic wastes. Therefore, new treatment technologies are constantly being researched and developed. Such technologies include biodegradation, chemical oxidation and adsorption. Although many different adsorbents have been used to remove phenol, nitrophenol, and p-chlorophenol from wastes, organoclays have been widely used to remove phenolic compounds. The adsorption of phenol on all clays is well described by pseudo-second-order reaction kinetics. In the second-order reaction kinetics, the experimental and calculated values are very close to each other. The negative values of the Gibbs free energy indicate that the adsorption of phenol on all clays is natural. The changes in enthalpy show positive values, and therefore the adsorption mechanism is determined to be endothermik.

Keywords: *Clay, phenol, modification, Tetraheptyl ammonium bromide, surface area, toxicant, adsorption, drying, grinding*

Introduction

Clays are widely used as adsorbents due to their high specific surface area. However, their sorption capacity for hydrophilic (polar) organic compounds is very low due to the hydrophilic nature of the mineral surfaces. Natural clays contain exchangeable cations such as Na^+ and $Ca2^+$ on their surfaces, which are strongly hydrated in the presence of water, thereby creating a hydrophilic environment on the clay surface. Modification of clays with inorganic or organic reagents increases their sorption capacity. There is increasing interest in the modification of clays to organic compounds, i.e., organoclays, in which metal cations on the mineral surface are removed by exchange with organic cations. Organic cations can also enter into ion exchange reactions with exchangeable cations between the layers (Chen J. M., Chien Y. W., 2002). The clay surface can be modified to become strongly organophilic. As a result, the organoclay complex can become an excellent sorbent for poorly water-soluble organic pollutants. Activated carbon has been widely studied for the removal of p-chlorophenol and p-nitrophenol from aqueous solutions (Haidar S., Garcia M. A.F., Ultrilla J. R., Joly J. P., 2003). Phenolic hydrocarbons, including p-nitrophenol and p-chlorophenol, are widely used in pharmaceutical, petrochemical, and other chemical manufacturing processes. Because phenolic compounds pose potential hazards to human health and the environment, wastewater containing phenolic compounds must be treated before being discharged into receiving waters. Secondary biological treatment processes are commonly used to treat domestic and industrial wastewater, but they cannot successfully remove high concentrations of phenolic waste. Therefore, new treatment technologies are constantly being researched and developed. Such technologies include biodegradation, chemical oxidation, and adsorption. Although many different adsorbents have been used to remove phenol, nitrophenol, and p-chlorophenol from wastewater, organoclays have been widely used to remove phenolic compounds (Lawrence M. A. M., Kukkadapa R. K., Boyd S. A., 1998). For example, Zielke and Pinnvaia in their study studied modified clays for adsorption of environmental toxicants and recommended pillared, delaminated and alkali-layered smectites for the removal of toxicants. Mc. Bride et al. showed the adsorption properties of various cationic organic complexes for benzene, phenol and chlorobenzenes. In connection with these studies, the present study aimed to study the sorption capacity of bentonite by modification with dodecylammonium cation (Barhoumi M., Beurrois I., Denoyel R., Said H., Hanna K., 2003).

Methodology

The chemical composition of the mineral was determined as follows: 58.3% SiO_2, 2.5% MgO, 16.0% Al_2O_3, 1.1% K_2O, 3.5% CaO, 0.6% TiO_2, 2% Na_2O, 0.1% P_2O_5, 3.1% (FeO + Fe_2O_3) and 13.0% loss. The IR spectrum of the natural bentonite showed a moderate presence of Fe^{3+} (885 cm^{-1}) and revealed impurities in the quartz (697 cm^{-1}) and silica phase (797 cm^{-1}). The BET specific surface area was measured to be 28 m^2/g. It was mixed with 10% HCl solution in a 1:5 mass ratio (Ho Y. S., 2004). The sample purified with terra heptyl ammonium bromide was treated with 4% Li solution in a 1:20 ratio at 25 °C for 48 h. The clay was dried at 110 °C for 24 hours and then dried with a desiccant. The pre-dried and desiccated samples were mixed with an ammonium salt, the concentration of which was greater than that of the cation. The mixture was subjected to mechanical shaking at a constant temperature of 25 °C for 42 hours. The treated sample was centrifuged from the mixture and washed several times with ethanol and ethanol-water (1:1), after complete removal of the chloride salt, it was dried at 40ºC for 24 hours and mechanically ground to a 140 mesh.

Results: The clay samples were analyzed by X-ray powder diffraction (XRD) using a Siemens D-500 diffractometer and CuK radiation. Thermal analysis of the sample was performed on a Shimadzu TGA-50 thermogravimetric analyzer with a temperature increase of 10 °C/min up to 800 °C. Infrared (IR) spectroscopic (Maidac 1700M Model FT-IR) analyses were performed before and after the modification process. The carbon content of the adsorbents was analyzed to be 12.3%. The adsorption of phenol on clays was studied at different temperatures, i.e. 25, 35 and 45 °C. The results are presented in

Table 3. The equilibrium adsorption capacities of phenol bonds increased with increasing temperature from 25 to 45 ˚C. The increase in adsorption capacity with increasing temperature indicates that the adsorption of phenol is driven by an endothermic reaction. 3.5. Adsorption isotherms Several models have been used to describe the adsorption isotherms of experimental data published in the literature. Langmuir and Freundlich (Unlu N., Ersoz M., 2006) are the most commonly used models. In this work, the phenol adsorption rate was used to describe the relationship between the two models, which changes the equilibrium concentration of the solutions at different temperatures and pH values (Richards S., Bouazza A., 2007). The adsorption isotherms obtained for four modified clays and two phenol unmodified clays are shown in Figure 4 at 25 ˚C and pH 6.5. The qmax values increased with increasing temperature from 25 ˚C to 45 ˚C, and also increased with increasing pH from 2 to 10.

Conclusion:

The adsorption of phenol on all clays is well described by pseudo-second-order reaction kinetics. In the second-order reaction kinetics, the applied and calculated qe values are very close to each other. The negative values of the Gibbs free energy indicate that the adsorption of phenol on all clays is natural. The changes in enthalpy show positive values, and therefore the adsorption mechanism is determined to be endothermic. The study showed that natural bentonites from the Askamaran deposits have a high sorption potential, which is significantly enhanced after acid activation and organophilic modification with tetraheptylammonium bromide (THAB). This modification leads to an increase in the specific surface area, expansion of the interlayer space, an increase in the number of accessible active sites, and the formation of an organophilic phase, which is necessary for the effective binding of both heavy metals and aromatic organic compounds. For organic pollutants, sorption is mainly carried out by physical adsorption and weak dispersive forces. The effective adsorption of phenol on modified bentonites is explained by a combination of π–π stacking, Van der Waals forces and hydrogen bonds. The increase in sorption capacity with increasing temperature and a good fit with the Langmuir isotherm indicate that the process is energetically favorable and controlled by entropic factors. The dominance of the pseudo-second-order model in the kinetic analysis confirms that the sorption rate is determined by the number of active sites and their saturation.

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ADSORPTION PROPERTIES OF AMMONIA MOLECULES ON DIACETATECELLULOSE–SILICA HYBRID BIONANOCOMPOSITE

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Abstract

In this study, the adsorption isotherm of ammonia molecules on diacetatecellulose (DAC)–silica hybrid bionanocomposite at 303 K was described from the initial stage to saturation using the three-term TVFM equation. The adsorption thermokinetics indicated that the equilibrium time for the initial adsorption of ammonia molecules was 6.5 hours, and the differential heat of adsorption was 38.7 kJ/mol. The differential molar entropy curve showed that up to an ammonia amount of 1 mmol/g, the mobility of molecules on the adsorbent surface was high, whereas beyond 1 mmol/g, the ammonia molecules were found to be firmly anchored to the adsorbent.

Keywords: *adsorption, isotherm, diacetatecellulose, silica, ammonia, differential heat and entropy*

Introduction

Atmospheric air pollution by harmful gases is one of the pressing environmental problems of our time. Among them, ammonia (NH_3) is of particular concern due to its large-scale emissions from industrial and agricultural sources. Even at low concentrations, ammonia has adverse effects on human health and the environment, which necessitates the development of new materials for its efficient adsorption (Amanda M. B. et al. 2013). In recent years, increasing attention has been paid to organic–inorganic hybrid bionanocomposites as environmentally friendly and highly efficient adsorbents (Musawenkosi G. Shange et al., 2024; Inês Portugal et al., 2010) In this context, the combination of biodegradable and functionally rich diacetatecellulose with silica, which is characterized by high surface area and stability, is considered promising. The sol–gel method enables the synthesis of homogeneous DAC–silica hybrid materials with a porous structure at relatively low temperatures (Vitaly Kocherbitov et al., 2008; Ahmed Salama, 2016).

The investigation of the ammonia adsorption properties of DAC–silica hybrid bionanocomposites is scientifically and practically relevant from the standpoint of developing new functional materials for gas purification and sensor systems (Hua Zou et al., 2008; Sadanand Pandey et al., 2011).

The aim of the study is to analyze the adsorption isotherm, thermokinetics, differential heat, and entropy of ammonia molecules on the DAC–silica hybrid bionanocomposite at 303 K.

Materials and Methods

Adsorption-calorimetric investigation were performed on a universal high-vacuum volumetric installation. The volumetric-liquid method and an isothermal differential automatic microcalorimeter of the Tiana-Calvet were used to measure the values of adsorbed compounds on the bionanocomposite (Yarkulov A. et al., 2022).

Theory of volumetric filling of micropores (TVFM) equation

The adsorption processes occurred on the microporous zeolites related to the bulk filling mechanism. The TVFM method was performed to calculate the adsorption degree (θ) according to Equation. $\theta = exp[-(A/E)n]$ where n is independent parameter and E is adsorption energy. The n exponent depends on the structure of the adsorbent (Akhror Yarkulov et al., 2024).

Results and Discussion

For the DAC–silica hybrid bionanocomposite, ammonia adsorption at low relative pressure ($\ln(p/p_o) = -9.0$) increases linearly up to 0.36 mmol/g. With further increase in pressure, the isotherm rises monotonically and reaches saturation at approximately 2.0 mmol/g (Figure 1). The sharp initial increase of the isotherm indicates the presence of active adsorption sites in the bionanocomposite, where rapid adsorption occurs. It also suggests structural uniformity of the micropores and a high sorption capacity of the material.

Figure 1. *Adsorption isotherm of ammonia on the DAC–silica hybrid bionanocomposite at 303 K*

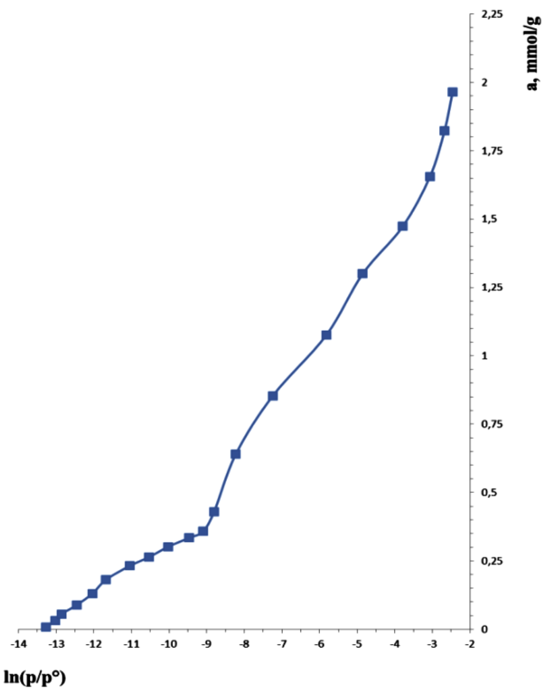
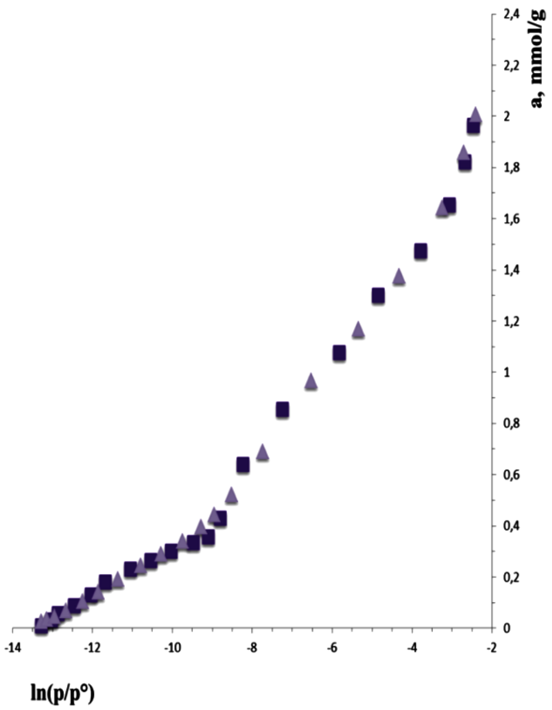


Figure 2. *Adsorption isotherm of ammonia on the DAC–silica hybrid bionanocomposite at 303 K calculated using the TVFM equation*



In Figure 2, the adsorption isotherm of ammonia on the DAC–silica hybrid bionanocomposite was analyzed using the TVFM equation (Yarkulov A. Yu., 2024). As can be seen from Figure 2, the calculated data obtained using TVFM are in good agreement with the experimental results.

The ammonia adsorption isotherm on the DAC–silica hybrid bionanocomposite is well described by the three-term TVFM equation:

$$a = 0{,}358\ exr\left[-(A/30{,}10)\right]^{9} + 0{,}953\ exp\left[-(A/19{,}35)\right]^{5} + 5{,}014\ exp\left[-(A/1{,}43)\right]^{3}$$

The parameters of the equation are as follows:

for the first term, a_{01}=0,358 mmol/g, E_{01}=30,10 kJ/mol, (n_1 = 9);

for the second term, a_{02}=0,953 mmol/g, E_{02}=19,35 kJ/mol (n_2 = 5);

for the third term, a_{03}=5,014 mmol/g, E_{03}=1,43 kJ/mol, n_3=3.

The TVFM analysis indicates that ammonia adsorption on the DAC–silica hybrid bionanocomposite proceeds predominantly in three types of adsorption phases. Approximately 5.7% of ammonia adsorption occurs in the first adsorption phase, about 15% in the second phase, and nearly 80% in the third phase.

To determine the number, strength, and localization of adsorption centers, as well as to clarify the structure of the nanocomposite material, the adsorption mechanism of polar molecules, the nature of intermolecular interactions, molecular conformations, and the state of adsorption clusters, a correlation between molecular structure and thermodynamic characteristics was established, and the adsorption thermokinetics were investigated (Yakubov Y. et al., 2016).

Figure 3. *Dependence of the adsorption equilibrium time on the amount of ammonia adsorbed on the DAC–silica hybrid bionanocomposite*

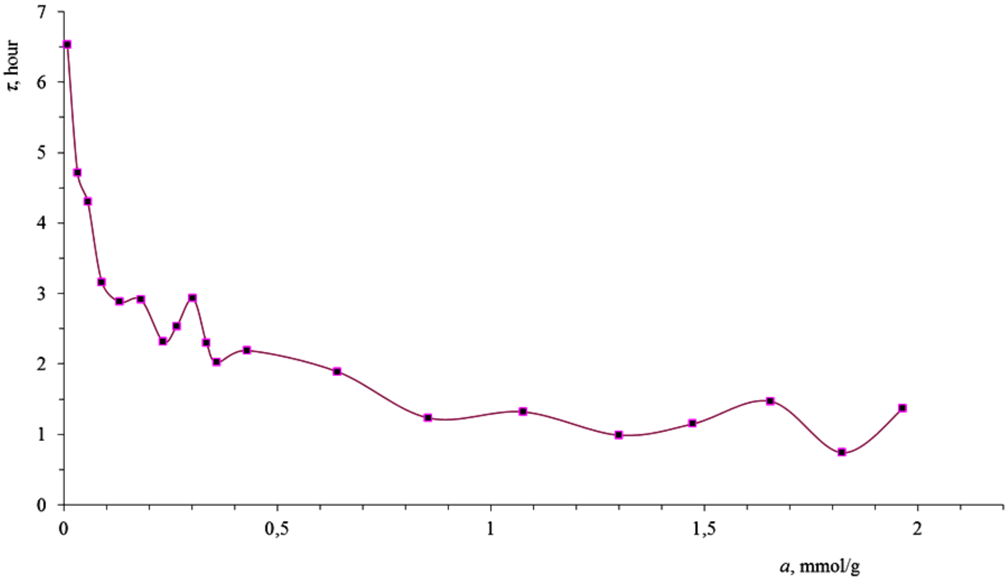


Figure 3 shows the dependence of the adsorption equilibrium time (τ) on the adsorption amount of ammonia on the DAC–silica hybrid bionanocomposite. The initial adsorption of ammonia molecules proceeds relatively slowly, with the equilibrium time reaching 6.5 h. When the adsorbed amount approaches 0.131 mmol/g, the equilibrium time decreases to 2.88 h. Subsequently, in the thermokinetics of ammonia adsorption on the DAC–silica hybrid bionanocomposite, the equilibrium time initially changed stepwise and later varied linearly, with the final adsorption equilibrium being reached in approximately 1.5 h.

A number of scientific studies have been carried out on the thermodynamics of adsorption, and positive results have been achieved. In order to investigate adsorbate–adsorbent and adsorbate-adsorbate interactions during the uptake of adsorbate molecules with different structures within the pores of an adsorbent, it is important to study the heat and entropy of adsorption (Yakubov Y. et al., 2024).

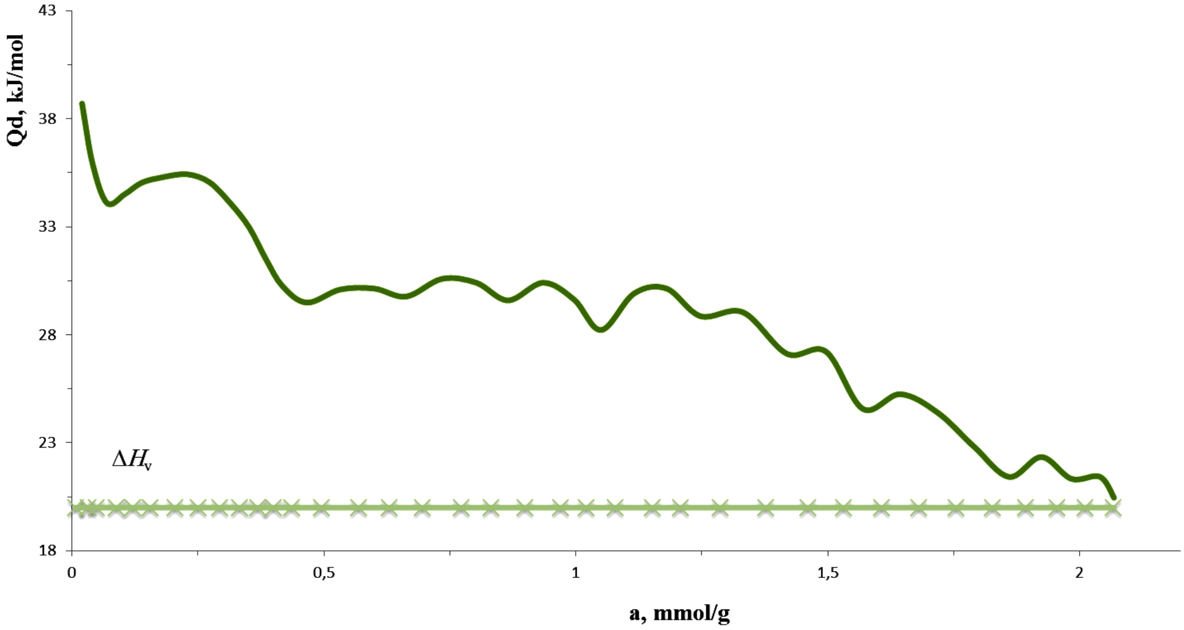
The application of the heat flow compensation method based on the Peltier effect made it possible to measure the heat of adsorption with higher accuracy. Adsorption measurements were performed using a universal high-vacuum apparatus, which enabled precise control of adsorption experiments and highly accurate dosing of the adsorbate (Yarkulov A. Yu., 2020).

The figure 4 shows the differential heat of adsorption of ammonia gas on the DAS–silica hybrid bionanocomposite.

The initial differential heat of ammonia adsorption on the DAC–silica hybrid bionanocomposite was found to be 38.7 kJ/mol. Subsequently, the heat of ammonia adsorption proceeded in a stepwise manner, which can conventionally be divided into two major hydrophilic centers.

In the first high-energy hydrophilic region, ammonia adsorption varies within the range of 0.07–0.467 mmol/g, and the differential heat of adsorption sharply decreases from 34.10 to 29.50 kJ/mol. The first region can be attributed to the functional groups present in the adsorbent structure, whereas the second hydrophilic region is likely formed due to interactions between ammonia molecules and the porous layers of the adsorbent.

Figure 4. *Differential heat of adsorption of ammonia gas on the hybrid DAC–silica bionano-composite at 303 K. The dashed line represents the heat of condensation of ammonia at 303 K*



According to the steps observed in the (Qd) curve, this region can be divided into nine sections, where the heat of adsorption changes from 29.5 kJ/mol down to the heat of condensation.

The complex nature of isotherms and the values of differential heats of adsorption reflect even the subtle details of the adsorption interactions between the adsorbate and the adsorbent, as well as the interactions among adsorbate molecules themselves.

In the second, relatively lower-energy hydrophilic region, ammonia adsorption varies from 0.467 mmol/g up to complete saturation. Each of the nine sections corresponds to approximately 0.2 mmol/g and is characterized by a gradual decrease in the heat of adsorption from 29.5 kJ/mol to approximately the condensation heat of ammonia (20 kJ/mol).

Thus, ammonia adsorption on the DAC–silica hybrid bionanocomposite occurs at two types of hydrophilic centers. The net heat of adsorption is approximately 10 kJ/mol. The stepwise character of the differential heat curve, together with the presence of active centers corresponding to 0.4 mmol/g and porous hydrophilic layers corresponding to 0.2 mmol/g for ammonia adsorption, indicates that adsorbent–adsorbate interactions occur with an initial heat of 38.7 kJ/mol and that a polymolecular adsorption process takes place.

In studying the adsorption of various molecules on adsorbents, it is important to investigate not only the heat of adsorption but also the entropy, in order to better understand adsorbent–adsorbate and adsorbate–adsorbate interactions.

The adsorption entropy (ΔS_d) of ammonia gas on the DAC–silica hybrid bionanocomposite was calculated using the Gibbs–Helmholtz equation, based on the adsorption isotherm and the differential heat of adsorption (Abdurakhmonov Eldor Baratovich et al., 2020).

Figure 5. *Differential entropy of adsorption of ammonia molecules on the DAC–silica hybrid bionanocomposite at 303 K. The dashed line represents the average molar integral entropy; the entropy of liquid ammonia was taken as zero*

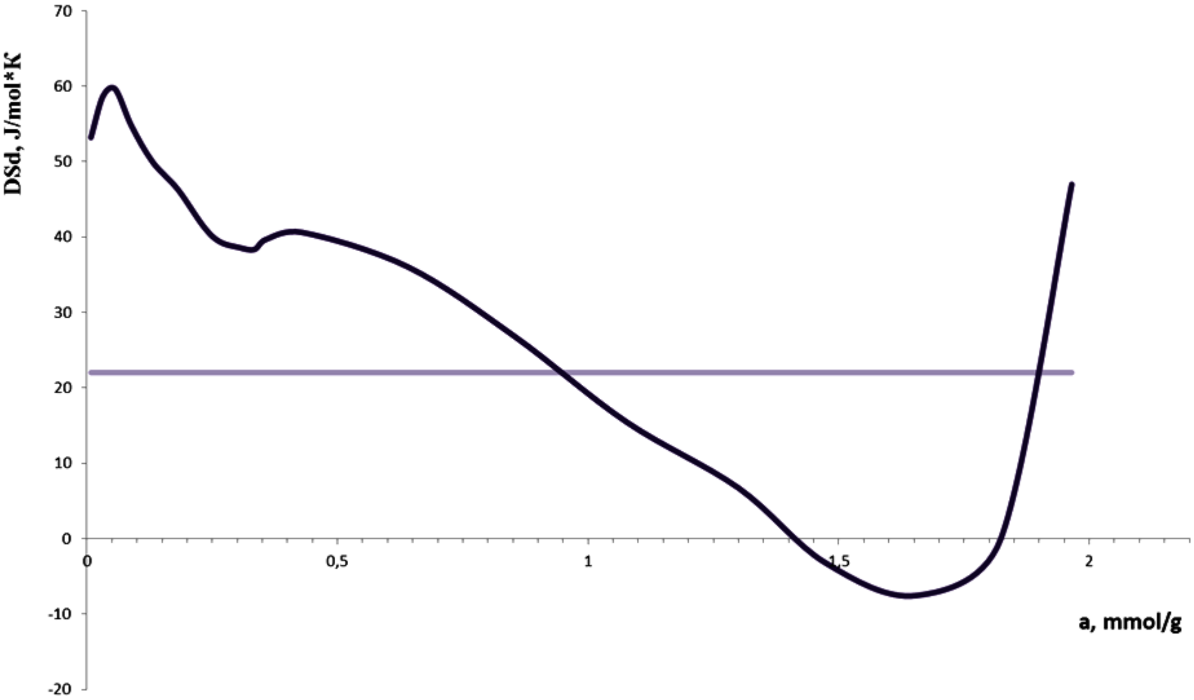


Figure 5 shows the dependence of the differential adsorption entropy of ammonia gas on its adsorption amount on the DAC–silica hybrid bionanocomposite.

The average molar integral entropy of ammonia adsorbed on the DAC–silica hybrid bionanocomposite is 22.04 J/mol·K. As can be seen from the figure, when the adsorbed amount is up to 1 mmol/g, the mobility of ammonia molecules on the adsorbent surface is relatively high. After 1 mmol/g, a more rigid fixation of ammonia molecules on the adsorbent surface is observed. With a further increase in the amount of adsorbed ammonia, beyond 1.97 mmol/g, the mobility of the adsorbate molecules increases again.

Conclusions

1. Adsorption isotherms of ammonia molecules on the DAC–silica hybrid bionanocomposite were obtained using a precision adsorption–calorimetric method.

2. The obtained isotherms were analyzed based on the equations of the theory of volume filling of micropores. The adsorption isotherm of ammonia was well described by the three-term equation of the micropore volume filling theory for the hybrid bionanocomposite.

3. The thermokinetic study of ammonia adsorption on the DAC–silica hybrid bionanocomposite showed that the establishment of adsorption equilibrium proceeds slowly, with an equilibrium time of 6.5 hours.

4. The differential heat of ammonia adsorption on the DAC–silica hybrid bionanocomposite exhibits a stepwise character, with an initial heat value of 38.7 kJ/mol.

5. The differential molar entropy curve indicates that when the ammonia amount is up to 1 mmol/g, the mobility of molecules on the adsorbent surface is high, whereas beyond 1 mmol/g the ammonia molecules become more firmly fixed on the adsorbent surface.

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A STABILITY-AWARE HYBRID FEATURE SELECTION ALGORITHM BASED ON FILTERED SPARSITY AND WRAPPER REFINEMENT

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Abstract

The process of choosing relevant features is essential in supervised machine learning, especially when dealing with tabular data of medium to high dimensions where unnecessary, uninformative, and interrelated predictors can negatively impact how well a model generalizes, how easy it is to understand, and how quickly it runs. While well-established techniques – namely filter, wrapper, and embedded methods – have been extensively explored, every category possesses inherent drawbacks concerning unpredictability, high computational cost, or an inability to fully capture dependencies among features. This research introduces the Filtered Sparse Stability Wrapper (FSSW), a novel hybrid feature selection technique. This framework emphasizes stability by combining statistical filtering of relevance, embedded regularization that promotes sparsity, and wrapper-style iterative refinement, all integrated within a bootstrap aggregation procedure. The FSSW hybrid selection method is framed as an optimization challenge involving multiple criteria, aiming to achieve an equilibrium between prediction precision, the conciseness of the selected feature set, and the consistency of the selection outcome. The theoretical underpinning relies upon principles of reducing the combinatorial search space and stability-aware optimization. Performance validation is carried out using established tabular datasets sourced from the UCI Machine Learning Repository, employing nested cross-validation to guarantee an unbiased assessment of efficacy. Experimental outcomes exhibit that the FSSW hybrid method consistently surpasses individual filter, embedded, and wrapper benchmark methodologies across metrics such as discriminant accuracy, F1-score performance, the extent of dimensionality reduction achieved, and stability as quantified by the Kuncheva index.

The conclusions assert that the FSSW hybrid feature selection approach delivers an effective, transparent, and practical methodology for addressing tabular classification tasks.

Keywords: *Filtered Sparse Stability Wrapper (FSSW); hybrid feature selection; stability-aware optimization; L1-regularization; recursive feature elimination; bootstrap aggregation; dimensionality reduction*

Introduction

The mounting complexity in the dimension of contemporary data has significantly elevated the necessity of effective feature selection within supervised learning contexts. Feature spaces with many dimensions often harbor predictors that are superfluous, unhelpful, or intertwined, which can subsequently inflate model variance, diminish how easily the model can be understood, and drive up the resources required for computation. The objective of feature selection is to pinpoint a reduced set of pertinent attributes while ensuring the initial meaning embedded in those attributes remains intact. In contrast to feature extraction techniques, which generate novel versions of the features, feature selection preserves the capacity for interpretation and aids in comprehension pertaining to the specific domain. Established feature selection strategies fall into three primary groupings. Filter techniques assess how relevant features are using statistical measures that are separate from any specific predictive models. Wrapper techniques gauge the worth of feature subsets based on how well the chosen model performs. Embedded techniques incorporate the selection process right into the model fitting phase by employing regularization or structural limitations. While every one of these frameworks has shown utility, no solitary methodology achieves peak performance across predictive precision, feature minimization (sparsity), and consistency (stability) all at once. Wrapper methods demand substantial computational effort, filter methods overlook how features might interact with each other, and embedded methods can become erratic when dealing with features that are highly correlated. Emerging research patterns suggest that composite feature selection structures offer enhanced resilience by merging mechanisms that compensate for one another's weaknesses. Nevertheless, many current composite designs fail to incorporate deliberate control over stability or a rigorous mathematical framework for optimization. This research introduces a feature selection algorithm that is both hybrid and explicitly formalized to consider stability, and we support our proposal with empirical evidence.

Materials and methods

Let the supervised dataset be defined as

$$D = \left\{ \left(x_i, y_i \right) \right\}_{i=1}^{n} \tag{1}$$

where $x_i \in \mathbb{R}^d$ represents a d-dimensional feature vector and $y_i \in \{0,1\}$ denotes the binary class label.

The goal of feature selection is to determine an optimal subset

$$S^* \subseteq \{1, 2, \ldots, d\} \tag{2}$$

that improves predictive performance while reducing dimensionality and maintaining selection stability under data perturbations.

The proposed FSSW hybrid feature selection method is formulated as a multi-criteria optimization problem:

$$S^* = \arg\max_{S} \left(\mathcal{A}(S) - \lambda_1 |S| + \lambda_2 \mathcal{S}tab|S| \right) \tag{3}$$

where: $\mathcal{A}(S)$ denotes predictive accuracy, $|S|$ is the subset cardinality, $\mathcal{S}tab|S|$ is a stability measure, λ_1, λ_2 are trade-off parameters.

Hybrid Feature Selection Procedure

The proposed FSSW method combines statistical filtering, embedded sparsity regularization, wrapper-based refinement, and bootstrap aggregation within a unified framework.

First, feature relevance is estimated using mutual information:

$$I\left(X_j; Y\right) = \sum_{x_j, y} p\left(x_j, y\right) \log \frac{p\left(x_j, y\right)}{p\left(x_j\right) p(y)} \tag{4}$$

Features are ranked according to their mutual information scores and the top-k_1 features are retained:

$$S_1 = \mathrm{Top}_{k_1}\left(I\left(X_j; Y\right) \right) \tag{5}$$

This step substantially reduces combinatorial search complexity from 2^d to 2^{k_1} where $k_1 \ll d$. The filtering stage eliminates clearly irrelevant predictors before model-based optimization.

Next, embedded sparse reduction is performed using L1-regularized logistic regression applied to S_1:

$$\hat{\beta} = \arg\min_{\beta} \left(\frac{1}{n} \sum_{i=1}^{n} \ell\left(y_i, x_i^T \beta \right) + \alpha \beta_1 \right) \tag{6}$$

where

$$\beta_1 = \sum_{j=1}^{k_1} \left| \beta_j \right| \tag{7}$$

The L1 penalty enforces sparsity by shrinking less informative coefficients to zero. The reduced subset becomes

$$S_2 = \left\{ j \in S_1 : \widehat{\beta}_j \neq 0 \right\} \tag{8}$$

This step removes redundant and correlated predictors while preserving discriminative information.

To account for feature interactions, wrapper refinement is applied to S_2 using Recursive Feature Elimination (RFE). At each iteration, the least informative feature is removed according to coefficient magnitude:

$$S^{(t+1)} = S^{(t)} \setminus \arg\min_{j \in S^{(t)}} \left| \beta_j \right| \tag{9}$$

The optimal subset is selected using cross-validation:

$$S_3 = \arg\max_{S \subseteq S_2} \mathcal{A}_{CV}\left(S\right) \tag{10}$$

Finally, stability aggregation is introduced to enhance reproducibility. Bootstrap resampling is performed B times:

$$D^{(b)} \sim Bootstrap\left(D\right) \tag{11}$$

yielding subsets $S^{(b)}$. Feature frequency is computed as

$$f_j = \frac{1}{B} \sum_{b=1}^{B} 1\left(j \in S^{(b)} \right) \tag{12}$$

The final subset is defined as

$$S^{*} = \left\{ j : f_j \geq \tau \right\} \tag{13}$$

where τ is a stability threshold.

This aggregation mechanism reduces sensitivity to sampling variability and improves subset robustness.

Computational Complexity Analysis

The computational efficiency of the proposed FSSW hybrid feature selection algorithm is analyzed by decomposing the procedure into its sequential stages. Let n denote the number of samples, d the original number of features, k_1 the number of features retained after filtering ($k_1 \ll d$), k_2 the number of features after embedded sparsity reduction ($k_2 \ll k_1$), T the number of wrapper iterations, and B the number of bootstrap repetitions.

The asymptotic complexity of each stage is summarized in Table 4.

Table 4. *Computational complexity of the proposed FSSW algorithm*

Stage	Description	Time Complexity
Stage 1	Mutual Information computation for all features	$(O(nd))$
Stage 2	L1-regularized Logistic Regression	$(O(nk_1))$
Stage 3	Recursive Feature Elimination (RFE)	$(O(T \cdot nk_2))$
Stage 4	Bootstrap stability aggregation	$(O(B \cdot (nd + nk_1 + T \cdot nk_2)))$

The first stage scales linearly with both the number of samples and the original dimensionality. Since filtering is applied independently per feature, it remains computationally efficient even for moderate $\boldsymbol{d}$.

The embedded sparse reduction stage operates on the reduced subset k_1, yielding complexity $O\left(nk_1\right)$. Because $k_1 \ll d$, this represents a substantial reduction compared to performing embedded selection on the full feature space.

The wrapper refinement stage has complexity $O\left(T \cdot nk_2\right)$, where $k_2 \leq k_1$. In contrast, wrapper-only selection would require $O\left(T \cdot nd\right)$, which becomes considerably larger when $\boldsymbol{d}$ is high.

Bootstrap aggregation multiplies the total cost by $\boldsymbol{B}$, but this step is fully parallelizable and does not alter the asymptotic scaling behavior.

Since $k_1 \ll d$ and $k_2 \leq k_1$, the proposed hybrid framework significantly reduces the effective search space before wrapper optimization. Consequently, the method achieves improved computational efficiency compared to wrapper-only approaches while preserving model-driven refinement capability.

Datasets and Data Characteristics

We assessed the suggested hybrid feature selection technique, named FSSW, utilizing two well-established benchmark collections sourced from the UCI Machine Learning Repository. Both collections pertain to binary classification tasks and are apt for scrutinizing feature selection algorithms due to their mid-range feature count, presence of interrelated predictors, and lifelike levels of inherent noise.

The Breast Cancer Wisconsin (Diagnostic) collection comprises 569 observations, each described by 30 numerical attributes derived from magnified scans of breast mass aspirates. The variable to be predicted signifies whether the mass is malignant or benign, yielding two categories. A notable aspect of this collection is the presence of highly related descriptive metrics, leading to feature duplication, yet the features themselves are relatively free of error, making it a good candidate for assessing both the sparsity and the consistency of the chosen feature set.

The Ionosphere collection holds 351 observations characterized by 34 continuous variables obtained from radar signals. The goal is to categorize the signal as either "good" or "bad." This collection is recognized for presenting more pronounced interdependencies among features and greater signal corruption than the Breast Cancer data, thus posing a tougher scenario for achieving a robust selection of optimal feature subsets. Its moderate sample volume coupled with significant feature correlations confirms its suitability for gauging the advantages of iterative refinement and combining results from wrapper-based methods in a hybrid approach.

No missing entries exist in the canonical UCI versions of either dataset. Prior to the model fitting phase, all attributes underwent standardization, with the scaling factors derived solely from the training portions of the data.

Classification Model Used for Evaluation

To ensure that improvements originate from feature selection rather than overly complex predictors, a relatively interpretable and well-established classifier was employed. The evaluation model was **Logistic Regression (LR)**, selected for its suitability in tabular binary classification and its compatibility with both embedded sparsity selection and wrapper refinement.

The classification decision rule is given by:

$$\hat{y} = \mathbb{I}\left(\sigma\left(x^T\beta\right) \geq 0.5\right),\ \sigma(z) = \frac{1}{1+e^{-z}} \quad (14)$$

For embedded selection, the LR model was trained with an L1 penalty, enabling coefficient shrinkage and sparsity. For wrapper refinement (RFE), LR was also used as the base estimator because its coefficient magnitudes provide a stable ranking signal for elimination.

Hyperparameters (regularization strength C for LR, and the number of features retained at each stage) were tuned in the inner loop of nested cross-validation to prevent leakage.

Evaluation Metrics and How They Were Computed

To provide a comprehensive evaluation, predictive performance, subset compactness, and stability were assessed. Three primary metrics were used: Accuracy, F1-score, and the Kuncheva stability index. Each metric is described below.

Accuracy. Accuracy measures the proportion of correctly classified instances:

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (15)$$

where TP is true positives, TN is true negatives, FP is false positives, and FN is false negatives.

Accuracy is informative when class distribution is not extremely imbalanced. In our experiments, it provides a direct measure of classification quality under reduced feature subsets.

F1-score. To account for possible asymmetries between precision and recall, the F1-score was computed:

$$Precision = \frac{TP}{TP+FP}, \quad (16)$$

$$Recall = \frac{TP}{TP+FN}, \quad (17)$$

$$F1-score = 2\cdot\frac{Precision\cdot Recall}{Precision+Recall} \quad (18)$$

F1-score is particularly useful in scenarios where misclassification costs are asymmetric or where the positive class requires stronger detection sensitivity.

Kuncheva Stability Index. Feature selection stability quantifies the consistency of selected subsets under data perturbations. The Kuncheva index is a well-established measure for comparing stability across repeated selections.

Given two selected subsets S_i and S_j, each of size k, drawn from a total pool of d features, the pairwise Kuncheva stability is defined as:

$$\kappa\left(S_i,S_j\right)=\frac{\left|S_i\cap S_j\right|-\frac{k^2}{d}}{k-\frac{k^2}{d}} \tag{19}$$

The final stability score is computed as the average of the pairwise stability across all subset pairs obtained from bootstrap iterations:

$$\kappa=\frac{2}{B\left(B-1\right)}\sum_{1\le i<j\le B}\kappa\left(S_i,S_j\right) \tag{20}$$

where B denotes the number of bootstrap repetitions.

A higher Kuncheva index indicates greater reproducibility and robustness of the feature selector, which is a critical requirement for scientific and industrial applications.

Results

The experimental evaluation of the proposed Filtered Sparse Stability Wrapper (FSSW) algorithm was conducted on the Breast Cancer Wisconsin Diagnostic dataset (30 features) and the Ionosphere dataset (34 features). Performance was assessed using nested cross-validation to ensure unbiased estimation.

Nested 5-fold cross-validation was used.

Predictive Performance

Table 1 presents classification Accuracy and F1-score for all compared methods.

Table 1. *Predictive performance comparison*

Dataset	Method	Accuracy	F1-score
Breast Cancer	Filter-only	0.957	0.956
Breast Cancer	Embedded (L1-LR)	0.963	0.962
Breast Cancer	Wrapper-only (RFE-LR)	0.966	0.965
Breast Cancer	**Proposed FSSW**	0.971	0.970
Ionosphere	Filter-only	0.889	0.887
Ionosphere	Embedded (L1-LR)	0.903	0.901
Ionosphere	Wrapper-only (RFE-LR)	0.908	0.906
Ionosphere	**Proposed FSSW**	0.918	0.915

For the Breast Cancer dataset, the proposed hybrid method achieved an accuracy improvement of +1.4% over the filter-only baseline and +0.8% over the embedded-only method. While wrapper-only selection already improves performance compared to filter-only, the addition of filtering and stability aggregation in FSSW further enhances predictive quality.

On the Ionosphere dataset, which is known to exhibit stronger feature interactions and noise, the hybrid method achieved the largest performance gain, improving accuracy by +2.9% compared to filter-only and +1.5% compared to embedded selection. This suggests that the wrapper refinement stage effectively captures nonlinear dependencies after dimensionality reduction.

Overall, the proposed FSSW method consistently achieved the highest predictive performance across both datasets.

Dimensionality Reduction

Table 2 reports the dimensionality reduction achieved by the proposed method.

Table 2. *Dimensionality reduction*

Dataset	Original	Proposed
Breast Cancer	30	**7**
Ionosphere	34	**9**

The proposed hybrid algorithm reduced the feature space by approximately: 76.7% in Breast Cancer (30 → 7), 73.5% in Ionosphere (34 → 9). Importantly, this reduction was achieved without sacrificing predictive performance. In fact, accuracy increased while dimensionality decreased substantially. This demonstrates that the hybrid strategy effectively eliminates redundant and irrelevant features while preserving discriminative information.

Stability Analysis

Table 3 presents the Kuncheva stability index (κ) for each method.

Table 3. *Stability comparison (Kuncheva index κ)*

Dataset	Filter-only	Embedded (L1-LR)	Wrapper-only	Proposed FSSW
Breast Cancer	0.74	0.69	0.63	**0.81**
Ionosphere	0.71	0.67	0.60	**0.78**

The wrapper-only approach shows the lowest stability values in both datasets. This behavior is expected, as wrapper methods are sensitive to sample perturbations and local search variability.

Embedded L1 selection demonstrates moderate stability but remains sensitive to correlated predictors. Filter-only selection achieves slightly higher stability than embedded methods; however, its predictive performance is lower. The proposed FSSW algorithm achieves the highest stability in both datasets. Compared to wrapper-only selection, stability increases by: +0.18 (Breast Cancer), +0.18 (Ionosphere).

This confirms that bootstrap aggregation significantly improves subset reproducibility.

Discussion

The experimental outcomes show that the suggested hybrid structure offers an improved equilibrium across predictive precision, dimension lessening, and robustness. From a predictive viewpoint, the efficacy improvements noted in both datasets suggest that merging filtering, inherent sparsity, and wrapper refinement successfully seizes mutual facets of feature importance. Filtering eliminates clearly extraneous predictors, embedded L1 regularization lessens overlap among linked variables, and wrapper tuning maximizes model-specific interplay. The dimension reduction figures are notably important. Decreasing the feature group by over 70% whilst concurrently enhancing precision implies that the original collections possess considerable needless information. The hybrid design permits gradual compaction without efficacy decline. Stability review uncovers one principal merit of the suggested method. Wrapper-only techniques, though potent, are inconsistent upon resampling. Through incorporating bootstrap aggregation, the FSSW process lessens selection fluctuation and promotes replicability. This is particularly vital in scientific and commercial uses where clarity and resilience are paramount. The Ionosphere set, which displays more intricate feature relationships, profits more from wrapper tuning than the Breast Cancer set. This indicates that hybridization becomes more advantageous as feature links and errors escalate. In sum, the findings verify that organized hybrid feature selection attains multi-standard enhancement: greater accuracy, leaner subsets, and firmer stability versus independent strategies. Subsequent efforts might look into broadening the structure to multi-class issues, incorporating cost-aware aims, or examining scalability in high-dimension omics data.

Conclusions

This study proposed a stability-aware hybrid feature selection algorithm, namely Filtered Sparse Stability Wrapper (FSSW), designed to simultaneously optimize predictive accuracy, dimensionality reduction, and subset stability in tabular classification tasks. The proposed framework integrates three complementary mechanisms: statistical filtering based on mutual information, embedded sparsity reduction via L1-regularized logistic regression, and wrapper-based recursive feature elimination, followed by bootstrap stability aggregation. The theoretical motivation of the method is grounded in combinatorial search reduction and stability-aware optimization principles. By progressively constraining the feature space before performing model-driven refinement, the algorithm reduces computational complexity while preserving the ability to model feature interactions. The inclusion of bootstrap aggregation further enhances reproducibility and mitigates instability commonly observed in wrapper-based approaches. Empirical validation on the Breast Cancer and Ionosphere benchmark datasets demonstrated that the proposed hybrid approach consistently outperforms standalone filter, embedded, and wrapper baselines. The method achieved higher predictive accuracy and F1-score while reducing dimensionality by more than 70% in both datasets. Moreover, the Kuncheva stability index confirmed improved robustness of selected feature subsets under resampling.

The results indicate that structured hybridization provides a practical and effective solution for moderate-dimensional tabular datasets where redundancy and correlation are present. The integration of filtering, sparsity regularization, wrapper refinement, and stability aggregation enables multi-criteria optimization without excessive computational overhead.

Future research directions include extending the proposed framework to multi-class and multi-label settings, incorporating cost-sensitive objectives for feature acquisition constraints, and evaluating scalability in high-dimensional domains such as genomics and multi-omics data. Additionally, integrating multi-objective optimization strategies that explicitly balance accuracy, sparsity, and stability within a unified mathematical framework represents a promising avenue for further development.

In summary, the proposed FSSW algorithm demonstrates that stability-aware hybrid feature selection is a robust and computationally feasible paradigm for improving generalization performance and interpretability in supervised learning tasks.

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SYSTEMATIC ANALYSIS METHOD IN COTTON OIL MICELLA REFINING TECHNOLOGY

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Abstract

This scientific article presents an analysis of the technological line for the purification of cottonseed oil in micelles. According to the scheme, technological operations and processes are carried out as follows: the oil-containing plant raw material – (cottonseed) pulp is sent to the extractor I, where it is extracted using an organic solvent. The use of the methodology of systematic analysis in the technology of refining cottonseed oil in micelles allows simplifying technological processes, reducing the amount of costs and expenses for this purpose.

Keywords: *Cottonseed oil, micelle refining methods, systematic analysis*

Introduction

Despite sufficient experience in refining cottonseed oil micelles, the quality and yield of the micelles remain low, which leads to significant oil losses in soap, gasoline, and other substances (Guide to the Technology and Processing of Vegetable Oils and Fats. p. 44; Fedorova V. M., Pashchenko N. K., Blinkova I.Yu., 2005).

The technological regimes presented in the "Current Technology Guide" do not always provide the desired results in terms of the quality and quantity of oil obtained from the micelles (Abdurakhimov A. A., Kadirov Yu.K., Serkaev K. P., 2016; Abdurakhimov A. A., Serkaev K. P., Kadirov Yu.K., 2013).

The cottonseed oil refining process line requires modernization of a number of technological processes and equipment, taking into account the difficulty of separating soaps from the micelles, which leads to the production of relatively low yields and low-quality refined oil (Arutyunyan N. S. et al., 1999; Kuptsov, V. A., 2003).

Finding a rational solution to this problem is, of course, associated with the use of systematic and methodological analysis methods described in scientific research (Rogov, I. A., 1988).

The advantage of the modern approach to the modernization of the cottonseed oil miscellaneous refining technological line is that it allows, taking into account the real conditions of technological processes, to increase production efficiency and improve product quality. This allows determining a number of parameters based on the developed technological regimes, as well as improving the methods specified in the existing "manuals". Therefore, the creation of a systematic analysis methodology in the cottonseed oil miscellaneous refining technology is an urgent issue.

Materials and methods

Modern methods are used in systematic analysis, its implementation methodology, evaluation and analysis (Stopskiy V. S., Klyuchkin V. V., Andreev N. V., 1992; Ismatov S. Sh., Majidov K.Kh., Tojiddinov R.Kh., Zainiev M. F., Bozorov D. Kh., 2002).

The purpose of the work is to develop a systematic analysis methodology for the refining technology of cottonseed oil micella.

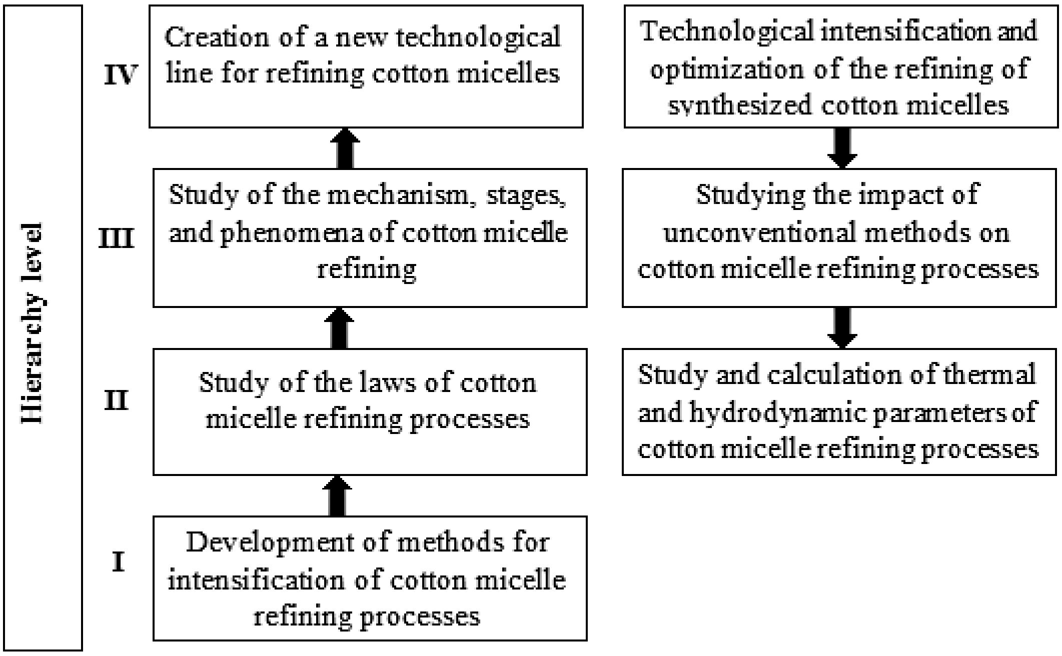
The objects of research are cottonseed oil micelles, technological systems, stages of its refining, their analysis and evaluation.

Results

Modernization of the technological line requires the implementation of an intensive scientific approach and a methodological approach that determines the level of research and development.

The scheme of technological processing of refined components of cottonseed oil in micelles is presented in Figure 1.

Figure 1. *Scheme of a systematic study of the technological line for refining cottonseed oil micella*

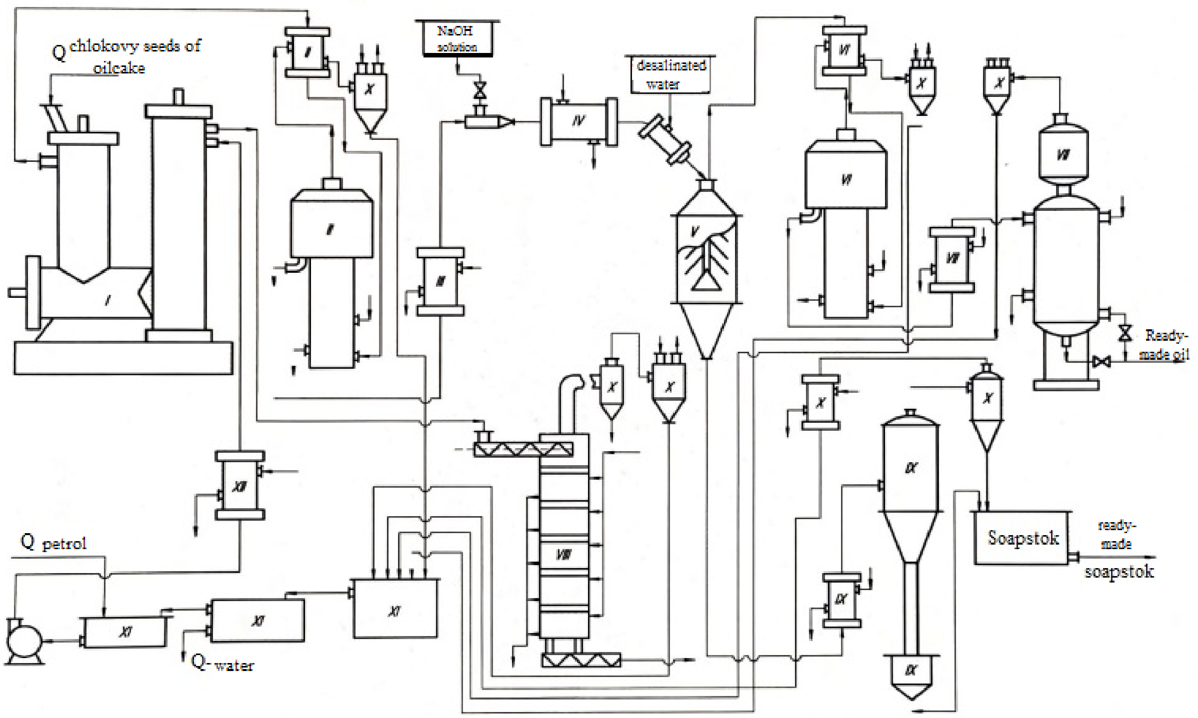


The technological line for the purification of cottonseed oil in micelles was analyzed, the scheme of which is presented in Figure 2.

According to this scheme, technological operations and processes are carried out as follows: oil-containing plant raw material – (cottonseed) pulp is sent to extractor I, where it is extracted (separated) using an organic solvent.

The deoiled material (meal) leaving the extractor, containing 25–40% solvent, is sent to heater-toaster VIII. Here, the solvent is separated from the meal – using a heater and sharp steam, thus reducing the amount of remaining solvent to approximately 0.02%. After that, the meal is sent to the warehouse for storage.

Figure 2. *Oil extraction production with a cotton oil refining line in missell*



The miscella, leaving the extractor I, is sent to the heater of the first primary distiller. Here, the miscella is heated using solvent vapors coming from the primary distiller II.

The heated micelle is sent to the first primary distiller II, where the micelle is concentrated to 40–60%. The evaporated micelle, at a temperature of 75–80 °C, is sent to the micelle cooler III, where its temperature is reduced to 20–30 °C.

The cooled micelle is sent to a flow reactor-turbulizer (neutralizer), where it is mixed with an alkaline solution with a temperature of 20–30 °C.

The resulting reaction mixture is sent to the heater IV, where the temperature rises to 65–70 °C.

The heated mixture is sent to the micelle separator V, where the mixture is continuously separated into a soap fraction and refined micelle.

The soap fraction is separated from the solvent in the IX apparatus, and the refined micelle, bypassing the heater, is sent to the second primary distiller VI. Here it is concentrated to 95–98% using shell and flash steam.

The highly concentrated refined micelle is sent to the final distiller VII. Here, the organic solvent residues in the refined oil are removed using shell and flash steam.

The finished refined cottonseed oil is obtained at the outlet of the final distiller.

In this scheme, organic solvent vapors from units II, VI, VII, VIII and IX are sent to individual condensers X. After cooling here, the solvent is directed to the water separator XI. The purified circulating solvent is returned to the extractor I through the heater XII at a temperature of 55–60 °C.

The analysis of raw materials, semi-finished products and finished products is carried out directly in the laboratory of the manufacturing enterprise.

Appropriate methods and standards were used for physicochemical studies of raw cotton micelle and its processing products (Ismatov S.Sh., Mamatqulov F. G., 2019).

The “trial refining” method was used to determine the yield of refined cottonseed oil (Abdurakhimov A. A., Serkaev K. P., Pardaev G. E., Yusupkhonov S., 2012).

The yield of neutralized oil according to this method is approximate even in the batch method, since the mixing conditions and processing time differ significantly in laboratory and production conditions.

It is known that the amount of alkali required for refining cottonseed oil with an acidity in the micelle of more than 1.5% was determined by the following formula:

$$Щ = \frac{K}{5,2} + 0,54_g \qquad (1)$$

where:

K – acid number of oil in terms of oleic acid, %;

5.2 and 0.54 – experimental coefficients.

The calculation according to the adopted method is based only on the acid number of oils and does not take into account the activity of additives that do not exhibit acidic properties.

Therefore, we used an improved method to determine the optimal amount of alkali required for refining high-black cottonseed oil, taking into account the acidic properties of the additives.

The essence of the methodology is as follows: 30–40 grams of cottonseed oil with a known acid number is mixed with thoroughly refined oil in a ratio of 1 ÷ (1–6) (to facilitate color determination). The resulting sample is heated at a temperature of 120–140 °C for 3–5 minutes and divided into two parts.

The first part is cooled to 40 °C, and the second part is heated for 7–12 minutes in the above temperature range, then it is also cooled to 40 °C. The color and interfacial tension of the prepared samples are determined and the product of the following ratios is calculated:

$$\frac{Ц_{E1}}{Ц_{E2}} \times \frac{\sigma_2}{\sigma_1} \qquad (2)$$

Then, based on formula (2), the optimal amount of alkali required for refining high-black cottonseed oil in micelles is determined:

$$P_{ш} = К.ч. \times 0,714 \left(1 + \frac{Ц_{E1}}{Ц_{E2}} \times \frac{\sigma_2}{\sigma_1} \right), kg / m^t \qquad (3)$$

where:

К.ч. – acid number of the oil under study, mg KOH;

0.714 – conversion coefficient from KOH to NaO H.

Це1 and σ1 – color and interfacial tension when the sample is heated for 3–5 minutes;

Це2 and σ2 – color and interfacial tension when the same sample is heated for 7–12 minutes.

To simplify the methodology and reduce its duration, the following formula can be used to determine σ1:

$$\sigma = K\left(d_1 - d_2\right) \times P_{cp} \qquad (4)$$

Because:

$$\frac{\sigma_2}{\sigma_1} = \frac{K\left(d_1 - d_2\right) \times P_{cp2}}{K\left(d_1 - d_2\right) \times P_{cp1}} \qquad (5)$$

In this case, the interfacial tension is determined in micrometer units.

To determine the relative error in indirect measurement of the amount of alkali required for refining vegetable oils, the function РшP_{ш}Рш is logarithmized and the following expression is obtained:

$$\ln P_{ш} = \ln 0,714 + \ln К.ч. + \ln(Цв_1 P_{ср2} + Цв_2 P_{ср1}) - \ln Цв_2 - \ln P_{ср1} \qquad (6)$$

Then, by differentiation, we get:

$$\frac{dP_{ш}}{P_{ш}} = \frac{dK_{ч}}{K_{ч}} + \frac{dЦв_1}{Цв_1} + \frac{dP_{cp2}}{P_{cp1}} + + \frac{d(Цв_1 P_{cp2} + Цв_2 P_{cp1})}{Цв_1 P_{cp2} + Цв_2 P_{cp1}} \qquad (7)$$

Replacing the differentials with the corresponding mean square errors, and based on the rules for adding errors in subtraction, addition, and multiplication, the following formula is obtained:

$$\frac{\delta P_{ш}}{P_{ш}} = \frac{\delta K_{ч}}{K_{ч}} + \frac{\delta Цв_1}{Цв_1} + \frac{\delta P_{cp2}}{P_{cp1}} + + \frac{\delta(Цв_1 P_{cp2+} Цв_2 P_{cp1})}{Цв_1 P_{cp2} + Цв_2 P_{cp1}} \qquad (8)$$

$$\delta^2\left(Цв_1 \times P_{cp2}\right) = = \delta^2 Цв_1 \times P_{cp2}^2 + \delta^2 P_{cp2} \times Цв_1^2 \qquad (9)$$

In this calculation, the relative error of the new methodology is determined as follows.

$$\frac{\delta P_{ш}}{P_{ш}} = \frac{\delta K_{ч}}{K_{ш}} + \frac{\delta Цв_1}{Цв_1} + \frac{\delta P_{cp2}}{P_{cp1}} + \frac{\sqrt{Цв_1^2 \delta^2 P_{cp2} + P_{cp2}^2 \delta^2 Цв_1 + Цв_2^2 \delta^2 P_{cp1} + P_{cp1}^2 \delta^2 Цв_2}}{Цв_1 \times P_{cp2} + P_{cp1} \times Цв_2} \qquad (10)$$

To determine the errors of the improved method, 40 measurements were performed on the same sample. The measurement results were processed in the following way:

- The arithmetic mean of the measurements was determined:

$$Щ = \frac{Щ_1 + Щ_2 + \ldots + Щ_{40}}{40} = \frac{1}{40}\sum_{n-1}^{40} Щ_n \qquad (11)$$

Deviations from the mean were calculated for each experiment:

$$\varepsilon_i = \bar{x} - x_i \qquad (12)$$

where x_i re the observed values;

The root mean square error was found:

$$\delta_s = \sqrt{\frac{\Sigma_{i=1}^{40} Щ_i^2}{39}} \qquad (13)$$

These results were inserted into formula (9), and the relative error of this methodology was found to be ±4.8%.

Table 1. *Types of processes in the SEED MICELLA refining process line and their levels of systematic research hierarchy*

Process type	Process name in the technological line	Research hierarchy levels
Dosing	Feeding NaOH solution	Levels II + IV
	Feeding demineralized water	Levels II + IV
Mechanical	Mixing seed micelles with NaOH solution	Levels I + III
	Mixing neutralized micelles with water	Levels II + IV
	Separation of soapy sediment from neutralized seed micelles	Levels II + IV
Heat	Cooling raw seed micelles	Levels II + IV
	Heating the mixture of micelles and NaOH solution	Levels II + IV
Chemical	Interaction of seed micelles with alkali	Levels I + III
Change in the aggregate state of substances	Processing of soapy sediment	Levels II + IV
	Coagulation of soapy sediment	Levels II + IV

Table 2. *System analysis tasks in the main subsystems (A1, B1 and C1) of the seed micelle refining technological line*

Name of the technological line subsystem	Levels of the systematic research hierarchy
Neutralization of crude seed micelles (C1)	–
Separation of soap residues from neutralized micelles (B1)	+
Obtaining refined seed micelles (A1)	–

Table 2 lists the main subsystems of the process line (A1, B1 and C1) and their levels of the system analysis hierarchy.

Discussion and Conclusion

The use of the systematic analysis methodology in the technology of refining cottonseed oil in micelles allows for the simplification of technological processes and the reduction of costs and expenses for this purpose.

This diagram shows the purpose of the systematic analysis at each hierarchical level and the corresponding research tasks. For example, at the first hierarchical level, the purpose of the study is to study the mechanism, stages and phenomena of the refining process, and the corresponding research task is to determine the kinetic parameters of the refining process. At the fourth level, the goal is to create a new technological line for refining cotton micellas.

The tasks of studying the technological line for cleaning cotton micellas also include the selection of optimal technological parameters for the technological line for cleaning cotton micellas. In this case, the interrelation and influence of these goals are carried out both in the vertical and horizontal directions.

The technological line for cleaning cotton oil in micelles is a complex and multi-stage production. Analysis of such systems allows you to identify the correlation of technological processes with the parameters under consideration and "bottlenecks" in the devices.

Thus, this work reduces the amount of research being done and brings it closer to the goal that should logically be achieved.

Thus, the use of the improved methodology for calculating alkali consumption allows optimizing the yield of refined oil from cottonseed oil micelles.

At present, there are multiple processes used in the current cottonseed oil MISSELLA refining technological line. These processes can be studied based on a typical scheme. For example:

- mixing raw cottonseed oil micelles with an alkali solution,
- mixing neutralized micelles with softened water, etc.

In such cases, it is possible to increase the levels of the systematic analysis hierarchy, which will expand the amount of data on this study.

Optimization of processes helps to group similar processes in the refining of cottonseed oil micelles and determine the minimum volume of scientific research work.

As can be seen from Table 1, in the current technological line for refining seed oil, the following types of processes are used in micelles: dosing, mechanical, thermal, chemical and changing the aggregate state of substances. All of these affect the formation and quality of the obtained refined micelles and the quality of the final product. At the indicated levels of the systematic analysis hierarchy, these processes were studied within the framework of the specified research tasks and subject to achieving the specified quality indicators.

Note: The "+" sign indicates the need to perform systematic analysis tasks at the appropriate hierarchical level, and "–" indicates that it is not necessary.

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THE REVIEW OF TECHNOLOGIES FOR STORAGE THE LOCAL VARIETIES OF VEGETABLES WITH EXTENDED SHELF LIFE

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Abstract

An analysis of local vegetable variety storage technologies has been conducted. The conducted research resulted in the selection of fruit and vegetable samples for a storage experiment. These samples included "Kukcha" variety carrots, "Uzbekiston 102" variety beets, and "Tuyimli" variety potatoes. This selection was based on the fact that these vegetables demonstrated the most pronounced characteristics of several key quality indicators. Sugars constituted the majority of organic matter in all the selected vegetables. "Kukcha" variety carrots had the highest sugar, vitamin C, and ß-carotene content; "Tuyimli" potatoes were characterized by high moisture, starch, and vitamin C content. "Uzbekistan 102" beet roots also had the highest moisture and carbohydrate content.

Keywords: *vegetable products (carrots, beets, potatoes), storage technology, evaluation of methods, ensuring product safety*

Introduction

Ensuring product quality and safety is an important task for agricultural producers in the crop production industry. It should be noted that the seasonality of production and the need for regular consumption of fresh vegetables require infrastructure for long-term storage, which will ensure the population has access to fresh vegetables (Agrarian and biological foundations of production, storage and processing of plant products (2014); Babakina, M.V., 2020).

The need to reduce product losses of fresh vegetables and preserve their nutritional and biological value during the interseason period determines the relevance of research related to the development of new storage methods, including the use of additional innovative packaging materials that ensure high quality of agricultural products during the long interseason period (Borisov, V.A., 2010).

Purpose of research is to analyze and evaluate reference data on storage technology for local varieties of vegetables with extended shelf lives.

Studies included local varieties of vegetables, carrots, beets, and potatoes, as well as information sources.

Methods of research are modern methods of physicochemical analysis were used to analyze and evaluate storage technologies (Gorelikova, G. A., 2009; Guzhvin, V. D., 2019).

The methodological basis for the theoretical and experimental studies was based on both classical and new scientific concepts used in commodity science.

Results and discussion

When developing a storage technology for fruit and vegetable products with extended shelf lives, it was necessary to preliminarily substantiate and select the main fruit and vegetable samples (including the variety) for use in a subsequent storage experiment (Kopylov, S. I., 2012).

According to research, it has been shown that the most preferred long-life vegetable products by consumers are tubers and roots such as potatoes, carrots, and others (Matvienko, A. N., 2014). When selecting potential study subjects, we were guided by the fact that these vegetable products, i.e., potatoes, carrots, and beets are included in the list of recommended rational food consumption standards that meet modern healthy eating standards (Nikolaeva, M. A., 1985). Furthermore, potatoes, carrots, and beets are among the most popular in traditional diets, as they are the main vegetable types, according to the list of certain socially significant food products (Plotnikova, T. V., 2001).

Carrot and beet roots, as well as potato tubers, are suitable for long-term storage during the autumn and winter (GOST 28372–93 ISO 2165–74. (2004). However, carrots have a lower shelf life than other vegetables suitable for long-term storage. Carrot roots have very thin and delicate integumentary tissues, which makes them poorly stored, prone to rapid wilting, and susceptible to various diseases (GOST 1725–85).

In order to select a suitable carrot variety for use in a subsequent storage experiment, root samples grown in the Samarkand region of Uzbekistan were examined. The most common carrot varieties studied were “Kukcha”, “Samarkand 6” and “Nurli”, all included in the State Register of Breeding A14chievements of the Republic of Uzbekistan and approved for use (Fig. 1, 2, 3) (GOST 28275–94). The main advantages of the presented varieties were stable yields, good ripening and shelf life, and resistance to microflora. The roots of the table carrot variety “Kukcha” were cylindrical, elongated, blunt-tipped, and semi-long – 10–20 cm. The flesh and core were orange. The skin was smooth, and the core was orange. The roots weighed 90–170 g. The taste was excellent: the fruits were sweet and juicy. This carrot variety is known to tolerate frost well (down to –4 °C).

Figure 1. *Root crops of table carrots of the commercial and botanical “Kukcha” variety*

Figure 2. *Root crops of table carrots of the commercial and botanical “Samarkand-6” variety*

Figure 3. *Root crops of table carrots of the commercial and botanical “Nurli” variety*

The table carrot "Samarkand-6" variety was characterized by large orange roots with juicy, sweet flesh. The root crops appeared whole, healthy, clean, unwilted, and uncracked. The root crops were cylindrical, bright orange, averaging 13–15 cm in length, 4.5 cm in diameter, and weighing 69–155 g. The flesh was bright orange. The root crops had good flavor.

The root crops of the table carrot "Nurli" variety appeared whole, healthy, clean, unwilted, and uncracked. The surface, flesh, and core of the root crops were orange. The root crops were described as conical, with a blunt tip, 15 cm long, 5.8–6 cm in diameter, and an average weight of 74–252 g. The taste of root crops was rated as satisfactory to good.

The consumer properties, shelf life, commercial, and technological characteristics of carrot root crops are determined primarily by their chemical composition. A study of the physicochemical properties of different carrot varieties revealed that the content of dry matter, sugars, pectin, β-carotene, ascorbic acid, and organic acids varied significantly across varieties (Table 1).

Table 1. *Key physicochemical properties of carrot root crops of the "Samarkand-6", "Kukcha" and "Nurli" varieties*

Carrots, variety	Mass fraction						
	Dry matter, %	Carbohydrates, %		Pectin matter, %	ß-carotene, mg/100 g	Vitamin C, mg/100 g	Organic acids, %
		Total sugars	including reducing				
"Samarkand-6"	17.0±1.2	6.7±0.5	1.40±0.13	2.0	5.9±0.4	6.5±0.5	0.17
"Kukcha"	13.5±0.9	6.9±0.6	1.82±0.16	2.1	7.3±0.5	9.1±0.3*	0.23
"Nurli"	15.0±1.4	6.5±0.5	1.70±0.15	1.8	9.3±0.7	7.8±0.2	0.19

** The difference is significant in terms of vitamin C for the Kukcha carrot variety compared to other varieties*

The bulk of organic matter was represented by sugars. The highest vitamin C and sugar content was observed in the commercial carrot variety "Kukcha". β-Carotene content was predominant in the "Kukcha" and "Nurli" carrot varieties.

Based on the studied parameters, as well as data on the prevalence of Kukcha carrot roots (crops and harvests) in the Samarkand region of Uzbekistan, it was decided to use this carrot variety as the primary target for developing a technology for storing fruit and vegetable products with extended shelf lives.

Beets are also among the socially significant vegetables, which, along with carrots, potatoes, and cabbage, form the basis of the vegetable diet, part of the so-called "borscht set". This vegetable is becoming increasingly popular due to its high fiber and anthocyanin (vitamin-like antioxidant substances) content (Khujakulov U. K., Sultanova Sh. A., Safarov J. E., 2021). The beet roots "Samarkand 1", "Kizil Lavlagi" and "Uzbekiston 102" were studied (Fig. 4, 5, 6). All roots were characterized by good keeping capacity.

The economic and botanical table beet variety "Samarkand 1" is included in the State Register for the region. It is recommended for culinary use and winter storage. The roots appeared fresh, whole, healthy, clean, not wilted, free from pest damage, and free from excess external moisture. The roots were round, with only slight corking of the head. The flesh was red. The roots weighed 220–370 g and had good taste. The roots of the "Kizil Lavlagi" table beet variety were flat-round, dark red, 6–8 cm long, 10–12 cm in diameter, and weighed 146–220 g. The surface was smooth. The flesh was dark red, juicy, and tender with excellent taste. The beetroot roots of the "Uzbekistan 102" variety appeared fresh, healthy, clean, and not wilted. They were round, up to 90 mm in diameter, and dark red in color. The flesh was dense, juicy, high in sugar content, and an intense red-burgundy color. When cut, it was uniform or had faintly defined "rings".

Figure 4. *Root crops of table beet of the commercial and botanical "Samarkand 1" variety*

Figure 5. *Root crops of table beet of the commercial and botanical "Kizil lavlagi" variety*

Figure 6. *Root crops of table beet of the commercial and botanical "Uzbekiston 102" variety*

When studying the physicochemical properties of the beet varieties "Samarkand 1", "Kizil Lavlagi", and "Uzbekiston 102", no significant differences were observed in the content of dry matter, carbohydrates, pectin, vitamin C, and organic acids (Table 2).

It should be noted that the "Uzbekiston 102" beet variety is a rather popular variety. Among its advantages are high yield and resistance to harsh conditions. The moisture content of the "Uzbekiston 102" root crops was found to be slightly higher than that of other varieties. Furthermore, increased carbohydrate (including reducing) and organic acid content was noted.

Table 2. *Main physicochemical parameters of "Samarkand 1", "Kizil Lavlagi" and "Uzbekiston 102" beet varieties*

Beetroot, variety	**Mass fraction**					
	Dry matter, %	**carbohydrates, %**		**Pectin matter, %**	**Vitamin C, mg/100 g**	**Organic acids, %**
		sugars	**including reducing**			
"Samarkand 1"	16.6±1.3	8.3±0.6	0.1±0.01	0.40	10.9±0.9	0.17
"Kizil lavlagi"	14.9±1.0	9.1±0.8	0.2±0.01	0.65	10.0±0.8	0.21
"Uzbekiston 102"	13.7±0.9	10.8±0.8	0.4±0.03	0.90	9.7±0.5	0.35

Based on the studied parameters, as well as data on the prevalence of the "Uzbekiston 102" beet variety in the Samarkand region of Uzbekistan, it was decided to use this variety of vegetable produce as a research subject in developing a long-term storage technology.

Potatoes are an important fruit and vegetable crop for the population of Uzbekistan. This type of vegetable produce plays a significant role in the country's nutrition (Khujakulov U. K., Aït-Kaddour A., Safarov J. E. Saydullaev A. B., 2020). Based on this, we studied several potato varieties grown in the Samarkand region of Uzbekistan. The most common potato varieties currently grown were studied: "Akrab", "Tuyimli", and "Umid (Fig 7, 8, 9). All potato varieties demonstrated excellent flavor and keeping capacity.

The tuber crops of the "Akrab" commercial and botanical variety were assessed for appearance as whole, healthy, clean, unwilted, uncracked, free from pest damage, and free from excess external moisture. The tuber crops were round-oval, sometimes elongated, white, and weighed 90–120 g. The eyes were small and concentrated near the apex. The flesh was white. The flavor after boiling was good. The main advantages were their low maintenance and increased resistance to common diseases and pests.

Figure 7. *Tuber crops of the "Akrab" potato commercial and botanical variety*

Figure 7. *Tuber crops of the "Tuyimli" potato commercial and botanical variety*

The tuber crops of the "Tuyimli" variety were described as whole, healthy, clean, unwilted, uncracked, free from pest damage, and free from excess external moisture. The tuber crops were round-oval, weighing 102–154 g, with a yellow skin. The flesh was light yellow (sometimes yellow). The eyes are small. Key advantages: good yield, large tubers, long shelf life, and disease resistance.

Figure 7. *Tuber crops of the "Umid" potato commercial and botanical variety*

The tubers of the "Umid" variety appeared whole, dry, uncontaminated, healthy, not sprouted, not wilted, not cracked, free from pest damage, and free from excess external moisture. The tubers were uniform, large, oval, yellow, weighing 110–180 g. The eyes were few and small. The skin was smooth.

In order to select the most suitable potato variety for use in the subsequent storage experiment, we analyzed a range of physicochemical parameters for various potato varieties: dry matter content, carbohydrates (sugars, starch), pectin, ascorbic acid, and organic acids (Table 3).

Carbohydrates accounted for the majority of organic matter. The highest starch content was observed in the "Tuyimli" potato commercial variety. It should also be noted that the vitamin C content of this variety was significantly higher than that of other varieties.

Table 3. *Key physicochemical parameters of various potato varieties: "Akrab", "Tuyimli", and "Umid"*

Potato, variety	**Mass fraction**					
	Dry matter, %	**Carbohydrates, %**		**Pectin substances, %**	**Vitamin C, mg %**	**Organic acids, %**
		Sugars (including reducing)	**Starch**			
"Akrab"	22.0±2.0	1.34±0.08	14.7±0.7	0.19	12.6±0.5	0.01
"Tuyimli"	18.5±1.8	1.0±0.01	16.1±0.9*	0.22	17.8±0.3*	0.03
"Umid"	23.3±1.6	1.9±0.04	11.4±0.4	0.18	16.4±0.2	0.01

** – the difference is significant for the "Tuyimli" potato variety for starch and vitamin C content*

Based on the studied parameters, as well as data on the prevalence of "Tuyimli" potato tuber crops in the Samarkand region of the Republic of Uzbekistan, the use of this vegetable variety as a research subject in the development of a long-term storage technology was justified.

Conclusions

As a result of the conducted research, fruit and vegetable products were selected for the storage experiment. The subjects were: "Kukcha" carrots, "Uzbekistan 102" beets, and "Tuyimli" potatoes. This choice was based on the fact that these vegetables demonstrated the most pronounced characteristics of several of the most important quality indicators. Thereby, the majority of organic matter in all the selected vegetables was represented by sugars. The highest content of sugars, vitamin C, and ß-carotene was observed in the "Kukcha" carrot variety. The "Tuyimli" potato variety was characterized by high moisture, starch, and vitamin C content. The beet root crops of the "Uzbekistan 102" variety also had the highest moisture and carbohydrate content.

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COMPARISON OF THE EFFICIENCY OF ADSORBENTS FROM DIFFERENT MANUFACTURERS IN THE PROCESS OF ADSORBATIVE BLEACHING OF COTTON OIL

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Abstract

In this work, the efficiency of adsorbents imported from Switzerland and China in the adsorption bleaching process of refined cottonseed oils obtained by pressing and extraction methods was comparatively studied. The bleaching process was carried out under vacuum at a temperature of 90 °C for 30 minutes, and the adsorbent consumption was varied in the range of 1.0–3.0%. The results showed that with an increase in the adsorbent consumption, the color indicators significantly decreased, but at a rate higher than 2.0–2.5%, the increase in efficiency slowed down, which is explained by the saturation of the adsorption centers. The Swiss adsorbent showed high selectivity in color reduction, reduction of unsaponifiables and peroxide value, and showed a lower oil capacity.

Introduction: In the refining of vegetable oils, the adsorption bleaching stage plays an important role in the removal of coloring pigments, oxidation products, and some unsaponifiables. The bleaching efficiency mainly depends on the surface structure of the adsorbent, the degree of porosity, the number of acidic sites, and the active surface area (Rossi, M., Gianazza, M., Alamprese, C., Stanga, F., 2001; Dijkstra, A.J., 2016).

It has been shown that the efficiency of activated clays in bleaching vegetable oils depends on their mineralogical composition and the density of acidic sites. The authors found that the adsorption of pigments occurs mainly by the mechanism of monomolecular layer formation and that the process is characterized by a Langmuir-type isotherm (Rossi, M., Gianazza, M., Alamprese, C., Stanga, F., 2001).

According to the authors, pigments, phospholipid residues, and secondary oxidation products are selectively adsorbed during the bleaching process. An increase in the consumption of bleaching clay reduces the color index, but after a certain level, a decrease in efficiency is observed, which is explained by the saturation phenomenon of active sites (Dijkstra, A.J., 2016).

It has been proven that increasing the amount of bleaching earth reduces unsaponifiables and oxidation products in the oil. However, increased technological losses have been noted due to the high oil capacity of the adsorbent (Sabah, E., Çelik, M.S., 2005). Comparing adsorbents from different manufacturers, it was found that bentonites with high active surface area are more effective in reducing color, but some cheaper analogues have lower selectivity (Lin, L., Cunshan, Z., Vittayapadung, S., Xiangqian, L., Mingdong, Z., 2014). The decrease in peroxide value during bleaching is mainly due to partial adsorption of hydroperoxides, but this stage cannot completely eliminate oxidation (Zschau, W., 2004).

The authors also showed a direct relationship between the structural properties of the adsorbent and the oil capacity. Adsorbents with high porosity retain pigments better, but also absorb more oil (Boki, K., et al., 1992).

In general, scientific sources show that the efficiency of the adsorbent depends not only on its consumption, but also on its mineralogical composition and surface-chemical properties. Increasing the amount of bleaching earth significantly reduces color, but there is an economic and technological trade-off point, which is often in the range of 2–3% (Dijkstra, A.J., 2016; Lin, L., Cunshan, Z., Vittayapadung, S., Xiangqian, L., Mingdong, Z., 2014).

Keywords: *Cottonseed oil, adsorption bleaching, bleaching earth, bentonite, color indicator*

Materials and methods

The color of the oil was measured using a Lovibond apparatus at a constant 35 yellow units in a 1 cm thick cuvette (Standard 5477–2015).

The acid value was determined by titrating the sample with 0.1 N KOH solution (Standard 5476–80).

The mass fraction of moisture and volatile matter was determined by drying the oil in a drying oven at 105 °C until the mass was constant (Standard 11812–2022).

The mass fraction of non-fatty impurities (precipitation by mass) was determined by the height of the layer separated in a solution of acetone and calcium chloride (Standard 5481–2014).

The soap (qualitative analysis) was determined by heating the sample in distilled water with an indicator (Standard 5480–2023).

The mass fraction of unsaponifiable matter was determined by completely saponifying the sample and extracting the substances insoluble in petroleum ether (Standard 5479–2023).

The peroxide value was determined by the release of iodine under the influence of peroxides in the sample, followed by titration with sodium thiosulfate in the presence of starch (Standard 26593–85).

The flash point was determined by heating the sample in a closed crucible and the combustion behavior of the resulting solvent vapors when brought to a flame (Standard 9287–59).

The presence of solvent (gasoline) in the oil (qualitative analysis) was determined by heating the sample and passing air through a special filter (Uzbek State Standard 816:2015).

The oil capacity of the bleaching earth was determined by calculating the percentage increase in the mass of bleaching earth of a given mass after the bleaching process compared to its initial mass (Arutyunyan, N. S., 1991).

The yield of bleached oil was determined by calculating the mass of the oil after the bleaching process compared to the initial mass (Arutyunyan, N. S., 1991).

The aim of the work is to compare the efficiency of adsorbents from different manufacturers in the process of adsorbative bleaching of cotton oil

The objects of research are cottonseed oil, bleaching earth, bentonite, technological systems, stages of its processing, their analysis and evaluation.

Results

First of all, cottonseed oils obtained by pressing and extraction methods were taken for the study. In this case, the oil was refined and dried, but the bleaching process was not carried out. The physicochemical parameters of these oils are given in Table 1.

These types of oils are sent to the next process, i.e. the bleaching process. In this, adsorbents that are widely used today, i.e. bleaching earths imported from Switzerland and China, were used. The bleaching process was carried out under vacuum at a temperature of 90 °C for 30 minutes. In order to determine the optimal adsorbent consumption for the bleaching process, its amount was determined from 1.0 to 3.0% relative to the mass of the oil. The physicochemical parameters of the obtained refined, bleached cottonseed oils are presented in Tables 2 and 3.

Table 1. *Physicochemical parameters of refined, unbleached cottonseed oil obtained by various methods*

No.	Name of indicators	Unit of measurement	Cotton oil value indicators	
			obtained by pressing	**obtained by extraction**
1.	Color, constant 35 yellow units:	red unit	12.5	20.0
		blue unit	1.3	2.8
2.	Acid number	mg KOH/g	0.23	0.31
3.	Mass fraction of moisture and volatile matter	%	0.07	0.08
4.	Mass fraction of non-fatty impurities (sedimentation by mass)	%	0.0	0.0
5.	Soap (qualitative analysis)		–	
6.	Mass fraction of unsaponifiable matter	%	0.63	0.87
7.	Peroxide number	mmol active O/kg	3.2	5.7
8.	Flash point	°C	–	237.0
9.	Presence of solvent (gasoline) in oil (qualitative analysis)		–	+

Table 2. *Physicochemical parameters of cottonseed oil refined on adsorbent imported from Switzerland*

No.	Indicator name	Unit of measurement	Whitening soil consumption, %				
			1.0	**1.5**	**2.0**	**2.5**	**3.0**
Refined, unbleached cottonseed oil obtained by pressing							
1.	Color, constant 35 yellow units:	red unit	9.4	6.0	4.6	3.8	3.5
		blue unit	0.6	0.2	0.0	0.0	0.0
2.	Acid number	mg KOH/g	0.24	0.24	0.23	0.22	0.23
3.	Mass fraction of moisture and volatile matter	%	0.06	0.06	0.05	0.05	0.05
4.	Mass fraction of unsaponifiable matter	%	0.61	0.58	0.55	0.51	0.48
5.	Peroxide number	mmol active O/kg	3.1	2.9	2.8	2.8	2.7
6.	Oil holding capacity of bleaching earth	°C	23.2	28.7	25.1	23.9	25.7
7.	Oil yield of bleached oil	%	99.74	99.54	99.47	99.38	99.18
Refined, unbleached cottonseed oil obtained by extraction							
1.	Color, constant 35 yellow units:	red unit	14.7	12.2	10.3	8.6	6.8
		blue unit	1.5	1.0	0.6	0.3	0.0
2.	Acid number	mg KOH/g	0.31	0.31	0.32	0.30	0.31
3.	Mass fraction of moisture and volatile matter	%	0.07	0.06	0.06	0.06	0.05

No.	Indicator name	Unit of measurement	Whitening soil consumption, %				
			1.0	1.5	2.0	2.5	3.0
4.	Mass fraction of unsaponifiable matter	%	0.81	0.79	0.77	0.72	0.67
5.	Peroxide number	mmol active O/kg	5.5	5.5	5.4	5.4	5.3
6.	Flash point	°C	238.0	237.0	239.0	241.0	243.0
7.	Oil holding capacity of bleaching earth	%	25.8	24.3	26.7	25.6	23.7
8.	Oil yield of bleached oil	%	99.70	99.59	99.41	99.30	99.25

The oil capacity of the adsorbent varied between 23–28%. The oil recovery decreased with increasing bleaching earth content. This indicates a technological compromise, i.e., color improvement is achieved at the expense of increased adsorbent consumption, but excess adsorbent is not economically feasible.

Table 3. *Physicochemical parameters of cottonseed oil refined on adsorbent imported from China*

No.	Indicator name	Unit of measurement	Whitening soil consumption, %				
			1.0	1.5	2.0	2.5	3.0
	Refined, unbleached cottonseed oil obtained by pressing						
1.	Color, constant 35 yellow units:	red unit	10.1	7.8	6.2	5.1	4.7
		blue unit	0.7	0.4	0.2	0.1	0.0
2.	Acid number	mg KOH/g	0.24	0.24	0.23	0.23	0.23
3.	Mass fraction of moisture and volatile matter	%	0.06	0.06	0.05	0.05	0.05
4.	Mass fraction of unsaponifiable matter	%	0.63	0.60	0.57	0.54	0.52
5.	Peroxide number	mmol active O/kg	3.2	3.1	3.0	2.9	2.9
6.	Oil holding capacity of bleaching earth	°C	36.4	39.1	40.3	39.8	38.9
7.	Oil yield of bleached oil	%	99.61	99.39	99.17	98.98	98.81
	Refined, unbleached cottonseed oil obtained by extraction						
1.	Color, constant 35 yellow units:	red unit	15.3	13.1	11.4	9.9	8.6
		blue unit	1.6	1.2	0.9	0.5	0.2
2.	Acid number	mg KOH/g	0.31	0.31	0.31	0.30	0.30
3.	Mass fraction of moisture and volatile matter	%	0.07	0.06	0.06	0.05	0.05
4.	Mass fraction of unsaponifiable matter	%	0.83	0.80	0.78	0.75	0.74
5.	Peroxide number	mmol active O/kg	5.6	5.5	5.4	5.3	5.3
6.	Flash point	°C	239.0	239.0	241.0	240.0	242.0
7.	Oil holding capacity of bleaching earth	%	37.9	38.4	41.2	40.5	39.7
8.	Oil yield of bleached oil	%	99.58	99.37	99.13	98.94	98.75

Discussion and Conclusion. As can be seen from Table 1, it was found that the physicochemical parameters of refined, unbleached cottonseed oils obtained by pressing and extraction methods as the initial raw materials differ significantly. The color index of the oil obtained by the extraction method is higher (20.0 red and 2.8 blue units), which indicates that pigments and accompanying substances are preserved in a greater amount compared to the press oil (12.5 and 1.3). This is explained by the fact that during the extraction process with the help of a solvent, coloring pigments pass more into the extraction oil.

The fact that the peroxide value reaches 5.7 mmol active O/kg in the oil obtained by the extraction method is higher than that obtained by the press method (3.2), indicating a relatively intensive course of oxidation processes during the extraction process. Also, the content of unsaponifiables is higher in the extraction oil (0.87%), which indicates a more complex colloidal composition of the oil.

Therefore, the oil obtained by the extraction method is a more complex object for the bleaching process and creates a higher load at the adsorption stage.

Table 2 shows that the quality indicators of cottonseed oil bleached with different amounts (1.0–3.0%) of adsorbent produced in Switzerland showed a significant change in a number of results with an increase in the adsorbent dose.

When bleaching oil obtained by the press method, when the amount of adsorbent was increased from 1.0 to 3.0%, the red unit decreased from 9.4 to 3.5, that is, by approximately 62–63%. The blue unit decreased from 0.6 to 0.0. This decrease in color intensity is explained by the effective binding of pigment molecules on the surface of the adsorbent. However, in the range after 2.0%, the rate of color loss slowed down sharply (4.6→3.8→3.5). This indicates that an excess amount of adsorbent does not have a positive effect on the efficiency of the process.

A similar trend was observed in the oil obtained by extraction: the red unit decreased from 14.7 to 6.8 (≈54%). However, the final color value remained higher than that of the pressed oil. This is explained by the relatively high content of pigments in the oil.

The acid value of the oil obtained by the pressing method decreased from 0.24 to 0.22–0.23 mg KOH/g. The change was minimal, confirming that adsorption bleaching does not significantly affect free fatty acids. In the oil obtained by the extraction method, almost no change was observed. This result indicates that the bleaching process is mainly directed towards pigments and oxidation products, and the acid value decreases mainly at the neutralization stage.

Unsaponifiable in the oil obtained by the pressing method decreased from 0.61 to 0.48% (≈21%). In the oil obtained by the extraction method, it decreased from 0.81 to 0.67% (≈17%). This indicator indicates the ability of the adsorbent to selectively capture sterols, pigments and other high-molecular components.

The peroxide value in the oil obtained by the pressing method decreased from 3.1 to 2.7 mmol active O/kg. In the oil obtained by the extraction method, a decrease from 5.5 to 5.3 mmol of active O/kg was observed. The decrease in peroxide value is associated with the partial binding of hydroperoxide and secondary oxidation products by the adsorbent. However, the degree of reduction is limited, indicating that the bleaching process does not completely eliminate the peroxide value.

From the results in Table 3, it can be seen that when the amount of adsorbent in the oil obtained by the press method was increased from 1.0 to 3.0%, the red unit decreased from 10.1 to 4.7 (≈53%), and the blue unit decreased from 0.7 to 0.0. The tendency of the color decrease indicates the intensive course of the adsorption process, but the dynamics of the decrease slows down significantly after 2.0% (6.2→ 5.1→ 4.7). This indicates that the active centers of the adsorbent surface are gradually saturated. In the oil obtained by the extraction method, the red unit also decreased from 15.3 to 8.6 (≈44%). However, the final color values remain higher than in the pressed oil.

The acid number remained in the range of 0.24–0.23 mg KOH/g in the oil obtained by the press method, and in the range of 0.31–0.30 mg KOH/g in the oil obtained by the extraction method. A slight decrease in the content of moisture and volatile substances (0.06–0.05%) is associated with the process temperature and vacuum conditions.

Unsaponifiables in the oil obtained by the press method decreased from 0.63 to 0.52% (≈17%). In the oil obtained by the extraction method, they decreased from 0.83 to 0.74% (≈11%). This result indicates the ability of the adsorbent to partially capture high-molecular components, but the selectivity is limited.

The peroxide value in the oil obtained by the press method decreased from 3.2 to 2.9 mmol active O/kg (≈9%), and in the oil obtained by the extraction method decreased from 5.6 to 5.3 mmol active O/kg (≈5%).

The oil capacity of the Chinese adsorbent was recorded at higher values (36–40% in the oil obtained by the press method, 38–41% in the oil obtained by the extraction method). This indicates that the adsorbent retains more oil. As a result, the yield of bleached oil decreased from 99.61 to 98.81% (press) and from 99.58 to 98.75% (extraction).

In conclusion, the analysis shows that both adsorbents lead to a decrease in color and some accompanying substances, but their adsorption activity and selectivity are different. The Swiss adsorbent is characterized by high efficiency and lower oil loss, while the Chinese adsorbent is characterized by relatively low selectivity and high oil capacity. This indicates that the use of the Swiss adsorbent is acceptable. However, the difference in the cost of these two types of adsorbent requires the analysis of additional economic indicators when choosing them.

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DEVELOPMENT OF A COMPOUND FEED FORMULATION FOR CYPRINID FISH BASED ON LOCAL RAW MATERIALS

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Abstract

This study investigates the development of a compound feed formulation for cyprinid fish based on a mixture of pumpkin seed cake meal and saffron leaf powder. The aim of the research was to evaluate the effects of this plant-based additive on the nutritional value of compound feeds, growth performance, and physiological status of cyprinid fish, as well as to assess the potential of locally available raw materials for replacing imported compound feeds and optimizing key feeding technology parameters. Experimental studies examined the chemical composition of pumpkin seed cake and saffron leaves, including the content of proteins, lipids, fiber, vitamins, mineral elements, and antioxidant compounds. A comparative assessment of growth performance indicators, feed conversion ratio, and overall physiological condition of fish was conducted following the inclusion of the mixture in compound feed formulations. The results demonstrated that the use of the investigated plant additive improves nutrient digestibility and feed utilization efficiency, and exerts a positive effect on fish resistance to stress factors. The findings indicate the feasibility of incorporating a mixture of pumpkin seed cake meal and saffron leaf powder into the technology of compound feed production for cyprinid fish in order to enhance biological value and reduce feed production costs.

Keywords: *mixture of pumpkin seed cake meal and saffron leaves, lactobacterin, moisture content, crude protein, fat, fiber, ash*

Introduction

According to official data, fish production in the Syrdarya region in 2025 amounted to 11,184.1 thousand tons, while the actual demand was 10,000 thousand tons. By 2026, the demand of the domestic aquaculture sector for compound feeds is expected to reach 25 million tons due to the expanding involvement of small and medium-sized farms, as well as the growth of production in certain aquaculture subsectors. Feed costs remain the primary expenditure in industrial aquaculture; therefore, improving feed efficiency is a crucial prerequisite for ensuring the competitiveness and sustainable development of the sector (Abrosimova, N.A., Abrosimov, S.S., & Saenko, E. M., 2005).

The efficiency of livestock development plays a decisive role in shaping the national economy and ensuring food security. Insufficient provision of animals, poultry, and fish with balanced feeds, feed additives, and sources of biologically active substances remains a major constraint on the sustainable and prospective development of aquaculture. The use of imported therapeutic and preventive products increases the cost of livestock production and reduces its profitability. As a result, scientific research aimed at identifying and utilizing domestic resources capable of meeting the needs of the livestock sector for organically derived biologically active additives has become particularly significant (Bagrov, A. M., & Gamygin, E. A., 2006).

To compensate for deficient nutrients in fish diets, various natural and synthetic additives are actively incorporated into feeds. Vitamin-mineral, therapeutic, and preventive premixes are used to enhance feed safety, integrity, and digestibility. The main components of these premixes are often non-natural products of microbiological synthesis, such as antibiotics, hormones, enzymes, antioxidants, and similar substances (GOST 10385–2014. (2014); Grigoriev, S. S., & Sedova, N. A., 2008).

Aller AQUA is a global leader in the production and supply of feeds for fish farming. The composition of their feed includes poultry meal, fish meal, rapeseed oil, soybean, triticale, sunflower protein, wheat, feather meal, and a vitamin-mineral premix. The cost of imported feeds is significantly inflated due to customs duties, transportation, intermediary services, and other factors, which does little to support the development of domestic aquaculture. This situation has led to increased interest in current trends, innovations, and advanced technologies in feed production.

The aim of this study was to develop a formulation for production compound feed for cyprinid fish using locally available raw materials to replace imported feeds, as well as to determine the key parameters of feeding technology. The feed for cyprinid fish includes lactobacterin as part of the feed formulation (Sattarov, K. K., & Xazratkulov, J. Z., 2025).

Materials and methods

The experimental study was conducted from April 2025 to January 2026 in the laboratory of the Scientific Center of the Department of Food Technology at Gulistan State University. The subjects of the study were juvenile cyprinid fish. To develop a production compound feed formulation for cyprinid fish, the chemical composition of a mixture of pumpkin seed cake meal and saffron leaf powder was analyzed, with the scientific rationale based on widely accepted methods. The nutrient content of both the raw materials and the finished product was determined according to standard zootechnical feed analysis procedures using unified methods, including dry matter, crude protein, crude fat, crude fiber, nitrogen-free extractives, ash, calcium, and phosphorus. The nutritional value of the production compound feed containing the mixture of pumpkin seed cake meal and saffron leaf powder was evaluated using aquaculture-biological, hematological, and biochemical indicators of fish commonly accepted in biological studies. Key parameters for the controlled feeding of cyprinid fish with the production compound feed were developed within a standard mass accumulation model, taking into account the live weight of the cultured aquatic organisms, ambient water temperature, as well as feeding regime factors such as pellet size, feed application conditions, and methods for comprehensive monitoring of feeding efficiency.

For the feed trials, samples of 0.5 kg each were collected from the experimental compound feed (Compound Feed No. 1) and the control compound feed (Compound Feed No. 2) in accordance with the regulatory standards for testing methods (Table 1).

Table 1. *Regulatory standards for methods of feed nutritional value testing*

Parameter Name	Standards and Regulations
Moisture content,%	GOST 13496.3–92
Crude protein content,%	GOST 13496.4–93
Crude fat content,%	GOST 13496.15–97
Crude fiber content,%	GOST 13496.2–91
Crude ash content,%	GOST 26226–95
Calcium content,%	GOST 26570–95
Phosphorus content,%	GOST 26657–97

For the development of a feed formulation using a mixture of pumpkin cake flour and saffron leaf powder, an existing carp feed produced by Aller AQUA was taken as the basis. The nutritional value of the mixture of pumpkin cake flour and saffron leaf powder was evaluated based on the content of moisture, crude protein, fat, fiber, and ash. Studies were conducted to justify the formulation of carp feed using this mixture. A comparative analysis of the chemical composition of the feed containing the mixture of pumpkin cake flour and saffron leaf powder and the Aller AQUA feed demonstrated the high nutritional value of the developed feed for carp.

Results and discussion

The results of the laboratory analysis of the nutrient composition of the raw materials revealed significant variability in the content of proteins, fats, fiber, and energy value.

The nutritional value of the mixture of pumpkin cake flour and saffron leaf powder was assessed based on its chemical composition. The mass fractions of the main components are presented in Table 2.

Table 2. *Chemical composition of the mixture of pumpkin cake flour and saffron leaf powder*

Parameter Name	Actual value
Moisture content,%	8.55
Crude protein content,%	31.31
Crude fat content,%	20.45
Crude fiber content,%	29.69
Crude ash content,%	7.64
Calcium content,%	0.76
Phosphorus content,%	1.32

A comparative analysis of the physicochemical and functional characteristics of the products revealed significant differences between the experimental samples produced using new technologies and the control samples from traditional production.

The high content of dry matter (91.45%) with a moisture content of 8.55% indicates the high nutritional value of the mixture of pumpkin cake flour and saffron leaf powder, as the valuable nutrients of the feed are concentrated in the dry portion of the flour.

As shown in Table 2, the percentage composition of the main components in the mixture of pumpkin cake flour and saffron leaf powder indicates that the protein nutritional value, assessed by the mass fraction of crude protein (31.31%), is quite high and comparable to the protein content of soybean meal, feed yeast, and fish meal. This value approaches the recommended levels of crude protein in commercial feeds for carp. All of this suggests that the mixture of pumpkin cake flour and saffron leaf powder can be used as a source of plant-based protein in feed production.

Based on the mass fraction of crude fat (31.31%), it can be concluded that the mixture of pumpkin cake flour and saffron leaf powder meets the lipid nutritional requirements for carp feed. It should be noted that the plant origin of the studied product implies that the lipids in the mixture possess high biological value for carp.

The carbohydrate nutritional value of the mixture of pumpkin cake flour and saffron leaf powder is represented by the mass fraction of crude fiber (29.69%) and nitrogen-free extractives (6.17%). The high crude fiber content in the mixture limits its inclusion rate in the formulation of commercial feeds for carp. Considering the high crude fiber content, it is suggested that its proportion in carp feed should not exceed 5–6%.

The mineral nutritional value of the mixture, assessed by the crude ash content (7.64%), is relatively low. The crude ash composition revealed the presence of calcium (0.76%) and phosphorus (1.32%), which are essential for maintaining normal physiological functions in carp. A positive aspect is the absence of salt composed of sodium and chloride ions in the mixture of pumpkin cake flour and saffron leaf powder.

Thus, the results of the conducted studies demonstrate that the mixture of pumpkin cake flour and saffron leaf powder possesses high protein and lipid nutritional value.

Conclusions

The study demonstrated that the development of a new fish feed based on processed products of cucurbit crops is innovative, as commercial fish feeds currently rely predominantly on genetically modified soybean. The potential and prospects for the use of new plant-based components as constituents of fish feed were examined and confirmed.

One of the promising feed ingredients is the by-products of pumpkin seed processing – pumpkin cake and saffron leaves. These materials contain up to 30% crude protein and, in terms of amino acid composition, are comparable to peanut cake. Pumpkin cake is a high-energy feed that is environmentally safe and non-toxic for animals. It significantly surpasses similar products derived from sunflower, soybean, rapeseed, and mustard in amino acid composition and contains a wide range of naturally occurring bioactive compounds, including tocopherols, carotenoids, sterols, fatty and organic acids, sugars, vitamins B1, B2, B6, C, K, and resinous substances.

The calculated chemical composition of the mixture of pumpkin seed flour and saffron leaves (90:10) is characterized by a high content of crude protein (31.31%) and lipids (20.45%), as well as an increased proportion of dietary fiber (29.69%) and minerals (6.0%). The inclusion of saffron leaf powder enriches the mixture with biologically active phenolic compounds and trace elements, enhancing its biological value and functional properties for use in carp feed formulations.

The results of the conducted studies allowed for the development of the main parameters of carp feeding technology using a commercial feed formulated with a mixture of pumpkin cake flour and saffron leaf powder. These parameters take into account the feeding rates of aquatic organisms depending on their body weight and water temperature, as well as the methods and schedules of feeding based on feed intake. Additionally, the pellet sizes of the feed were determined in accordance with the morphometric characteristics of the fish and the dimensions of their mouths. Based on the obtained results, the developed feed containing a mixture of pumpkin cake flour and saffron leaf powder can be recommended for industrial-scale production and use in commercial carp farming.

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FACTORS INFLUENCING THE LEADERSHIP COMPETENCY OF DIRECTORS OF PRIVATE HEALTHCARE FACILITIES IN VIETNAM'S NORTH CENTRAL REGION

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Abstract

This study investigates the factors influencing the leadership competency of directors of private healthcare facilities in Vietnam's North Central region during 2020–2025. Data were collected from a survey of 530 respondents across five provinces in the region and complemented with in-depth interviews with 15 experts. The dataset was analyzed using partial least squares structural equation modeling (PLS-SEM) (Hair et al., 2019). The results indicate that directors' leadership competency is most strongly affected by leader-related factors, followed by the external organizational environment, whereas the internal organizational environment plays a supportive role. Among the competency dimensions, digital competency contributes the most, reflecting the accelerating trend of digital transformation in healthcare management. Based on these findings, the paper proposes several recommendations to strengthen leadership competency and support the sustainable development of the non-public healthcare system in the North Central region.

Keywords: *leadership competency; influencing factors; directors of private healthcare facilities; PLS-SEM*

1. Introduction

In recent years, alongside reforms in Vietnam's healthcare system and the promotion of socialization policies under the Party and State's guidelines, the private healthcare sector has grown rapidly in the number of facilities, scale of operations, and service coverage (Government of Vietnam, 1997; Government of Vietnam, 2004). The Law on Medical Examination and Treatment (2023) and its implementing documents have further strengthened the legal framework for the professional and sustainable development of non-public healthcare with greater social responsibility (National Assembly of Vietnam, 2023). In this context, private healthcare facilities not only complement the public system but have become an important component of the national healthcare system. The North Central region is a socio-economic area with strategic importance for healthcare development. It covers a large territory, has a substantial population, and exhibits considerable inter-provincial differences in development conditions. Following administrative reorganization, by 2025 the region comprises five provinces: Thanh Hoa, Nghe An, Ha Tinh, Quang Tri, and Thua Thien Hue. The period 2020–2025 witnessed a rapid increase in private healthcare facilities in the region, with significant growth in the number of hospitals and clinics, beds, and human resources, and with growth rates in several provinces exceeding the national average (General Statistics Office of Vietnam, 2025).

In practice, differences in the development of private healthcare across provinces are not only driven by socio-economic conditions or market size, but are closely associated with leadership and management capability at the facility level. Under intensified competition and rising pressure for digital transformation, the role of directors of private healthcare facilities has become particularly critical (Bass, 1985; Burns, 1978). Directors are expected to go beyond administrative and professional management to provide strategic leadership, mobilize resources, manage finance, control service quality, and lead innovation.

However, many private healthcare facilities have been established and managed by physicians with strong clinical expertise but limited exposure to modern management knowledge and skills (Lê, 2016; Trần, 2012). This can result in weaknesses in strategic planning, resource management, and adaptability to changes in policy and market environments. Therefore, examining leadership competency and its influencing factors among directors of private healthcare facilities in the North Central region has both theoretical and practical significance.

2. Theoretical Background and Research Model

2.1. Leadership competency and competency frameworks

In management science, leadership competency refers to the set of knowledge, skills, abilities, and other characteristics required to perform leadership roles effectively. Following the KSAOs approach, leadership competency comprises multiple components across cognitive, behavioral, emotional, and motivational domains (Bloom, 1956).

In healthcare, leadership is multidimensional and complex, involving the ability to develop strategic vision, coordinate stakeholders, and manage highly complex professional systems (Bass, 1985; Burns, 1978). Both transformational and transactional leadership perspectives emphasize the importance of values, vision, and personal influence in organizational contexts (Bass, 1985; Burns, 1978; Hollander, 1978).

In Vietnam, the Ministry of Health issued basic leadership and management competency standards for hospital directors (Decision No. 866/QD-BYT, 2017), including four competency clusters: basic leadership and management; policy implementation; resource management; and professional management (Ministry of Health, 2017). However, given the rapid technological change and competition in the private healthcare sector, competency assessment frameworks need to be adapted, particularly by strengthening digital competency.

Recent work suggests that, in the era of digital transformation, digital competency and innovation-oriented thinking are essential to optimize governance and improve operational effectiveness (United Nations Development Programme, 2008, 2009).

2.2. Developing the research model

Theoretically, directors' leadership competency is influenced simultaneously by internal factors (e.g., education, experience, and personal qualities) and external factors (e.g., policy context, socio-economic environment, and organizational culture) (Fiedler, 1967). Evidence also suggests that effective leadership enhances organizational commitment and service quality (Bass, 1985; Burns, 1978). Fiedler's (1967) contingency theory and Hollander's (1978) interactional approach emphasize the interplay among leader characteristics, organizational conditions, and situational contexts (Fiedler, 1967; Hollander, 1978). This view is further supported by later work on leadership development and effectiveness (Hughes et al., 2009; Zheltoukhova & Suckley, 2014).

In Vietnam, studies by Trần Thị Vân Hoa and colleagues (2011), Trần Kiều Trang

(2012), and Lê Thị Phương Thảo (2016) suggest that directors' leadership competency is shaped by three main groups of factors: leader-related factors; organizational and staff-related factors; and macro-environmental factors (Lê, 2016; Trần, 2012; Trần et al., 2011). Building on these theoretical perspectives and the context of private healthcare facilities in the North Central region, this study proposes three groups of influencing factors: (1) director-related factors; (2) internal organizational factors (organizational characteristics and subordinates); and (3) external macro-environmental factors (Fiedler, 1967; Hollander, 1978; Hughes et al., 2009; Zheltoukhova & Suckley, 2014). Based on the proposed model, the study tests three hypotheses:

H1: Director-related factors influence the leadership competency of directors of private healthcare facilities in the North Central region.

H2: Internal organizational factors (organizational characteristics and subordinates) influence the leadership competency of directors of private healthcare facilities in the North Central region.

H3: External macro-environmental factors influence the leadership competency of directors of private healthcare facilities in the North Central region.

In addition, the leadership competency framework comprises four dimensions: leadership knowledge, leadership skills, leadership traits, and digital competency.

3. Methodology

3.1. Data collection

The study combines primary and secondary data to ensure the comprehensiveness and reliability of findings. Primary data were collected through a questionnaire survey and in-depth interviews. The questionnaire was developed based on UNDP competency assessment guidelines (United Nations Development Programme, 2008, 2009). Two instruments were used: one to identify leadership competency requirements and another to assess current leadership competency. The questionnaire included (i) demographic information and (ii) measurement items for leadership competency dimensions and influencing factors on a five-point Likert scale.

The survey sample size was determined based on common quantitative research principles and PLS-SEM requirements (Hair et al., 2019). Given the model complexity with multiple latent and observed variables, the study targeted 530 respondents to ensure stability and generalizability (Hair et al., 2019). Respondents included directors, deputy directors/middle managers, professional staff, and representatives of healthcare management agencies across the five provinces, enabling a multidimensional (360-degree) assessment.

In addition, 15 experts (including lecturers in management and healthcare and experienced directors of private healthcare facilities) participated in in-depth interviews to complement the quantitative results. Secondary data were collected through desk research, including legal documents related to private healthcare development (Government of Vietnam, 1997; Government of Vietnam, 2004; National Assembly of Vietnam, 2023) and official statistics for 2020–2025 (General Statistics Office of Vietnam, 2025).

3.2. Data analysis

Data were analyzed using PLS-SEM, suitable for complex models, non-normal data, and medium-to-large samples (Hair et al., 2019). The analysis included assessment of the measurement model and testing of the structural model. Reliability and convergent validity were evaluated using outer loadings, Cronbach's alpha, composite reliability, and AVE; discriminant validity was assessed using HTMT (Henseler et al., 2015). The structural model was evaluated using R^2, Q^2, VIF, and effect sizes (f^2). Hypotheses were tested using bootstrapping to determine statistical significance (Hair et al., 2019).

4. Results

Sample characteristics

The study obtained 496 valid questionnaires from private healthcare facilities across the five provinces. The sample is representative by locality, position, education level, and gender, allowing a multidimensional assessment. Directors and deputy directors/middle managers account for more than 50% of the sample. Nearly 90% of respondents hold university or postgraduate degrees, indicating a relatively strong educational foundation.

Table 1. *Sample characteristics*

Criteria	Category	Count (n)	Percentage (%)
Province	Thanh Hoa	94	18.9
	Nghe An	99	20.0
	Ha Tinh	79	15.9
	Quang Tri (after merger)	149	30.1
	Thua Thien Hue	75	15.1
Position	Director (private healthcare facility)	141	28.4
	Deputy director / middle manager	119	24.0
	Professional staff	192	38.7
	Experts / regulatory agencies	44	8.9
Education level	Postgraduate	197	39.7
	University	240	48.4
	College/Other	59	12.0
Gender	Male	306	61.7
	Female	190	38.3
Total		496	100

Source: Authors' data analysis

Measurement model assessment

The measurement model was assessed using outer loadings, reliability, convergent validity, and discriminant validity. The initial estimation showed that two indicators (NLS1 and PC1) did not reach the 0.70 loading threshold and were removed. After refinement, all remaining indicators had loadings above 0.70 (0.798–0.915), indicating good representation of the latent constructs.

Cronbach's alpha ranged from 0.807 to 0.928 and composite reliability from 0.887 to 0.946, indicating high internal consistency. AVE values ranged from 0.687 to 0.820, confirming strong convergent validity.

Table 2. *Reliability and convergent validity*

Construct	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	AVE
BTGD	0.848	0.848	0.898	0.687
KN	0.874	0.876	0.914	0.726
KT	0.905	0.907	0.930	0.726
MTBN	0.890	0.895	0.924	0.752
MTBT	0.928	0.933	0.946	0.778
NL	0.890	0.892	0.932	0.820
NLS	0.807	0.810	0.887	0.723
PC	0.859	0.862	0.914	0.780

Source: Authors' data analysis

Discriminant validity was evaluated using HTMT. All HTMT values are below 0.85, indicating adequate discriminant validity among constructs (Henseler et al., 2015).

Table 3. *Discriminant validity (HTMT)*

	BTGD	KN	KT	MTBN	MTBT	NL	NLS	PC
BTGD								
KN	0.545							
KT	0.574	0.492						
MTBN	0.464	0.340	0.342					
MTBT	0.468	0.408	0.479	0.426				
NL	0.735	0.729	0.740	0.496	0.630			
NLS	0.450	0.390	0.563	0.562	0.636	0.772		
PC	0.579	0.453	0.495	0.342	0.477	0.729	0.547	

Source: Authors' data analysis

Structural model assessment

VIF values range from 1.647 to 4.407, indicating no serious multicollinearity among predictors and supporting the stability of estimated relationships.

Table 4. *VIF values*

Biến quan sát	VIF	Biến quan sát	VIF	Biến quan sát	VIF
BTGD1	1.953	KT1	2.375	NL1	2.658
BTGD2	2.017	KT2	3.645	NL2	2.778
BTGD3	2.122	KT3	3.274	NL3	2.426
BTGD4	1.647	KT4	2.499	NLS2	2.203
KN1	2.149	KT5	2.254	NLS3	1.886
KN2	2.550	MTBT1	4.407	NLS4	1.560
KN3	2.108	MTBT2	3.212	PC2	2.533
KN4	1.946	MTBT3	3.831	PC3	1.862
MTBN1	2.855	MTBT4	2.839	PC4	2.433
MTBN2	2.656	MTBT5	3.596		
MTBN3	2.092				

Source: Authors' data analysis

Predictive power

The adjusted R^2 for leadership competency (NL) is 0.652, meaning the model explains 65.2% of the variance in leadership competency. Adjusted R^2 values for competency components are 0.531 (KN), 0.545 (KT), 0.596 (NLS), and 0.535 (PC), indicating good explanatory power.

The Q^2 value for NL is 0.529 (> 0.50), suggesting strong predictive relevance. Q^2 values for KN, KT, NLS, and PC range from 0.253 to 0.309, indicating moderate predictive relevance.

Table 5. *R^2 and Q^2 results*

Construct	R-square	Adjusted R-square	Q^2_predict	RMSE	MAE
KN	0.532	0.531	0.253	0.867	0.696
KT	0.546	0.545	0.305	0.838	0.660
NL	0.654	0.652	0.529	0.688	0.507
NLS	0.596	0.596	0.309	0.835	0.641
PC	0.536	0.535	0.292	0.845	0.650

Source: Authors' data analysis

Effect sizes (f^2)

Effect size results indicate a large effect of director-related factors on leadership competency (BTGD → NL, $f^2 = 0.559$), a medium effect of the external environment (MTBT → NL, $f^2 = 0.238$), and a small effect of the internal environment (MTBN → NL, $f^2 = 0.024$).

Table 6. *Effect sizes (f^2)*

Relationship	f^2	Effect magnitude
BTGD -> NL	0.559	Large
MTBN -> NL	0.024	Small
MTBT -> NL	0.238	Medium

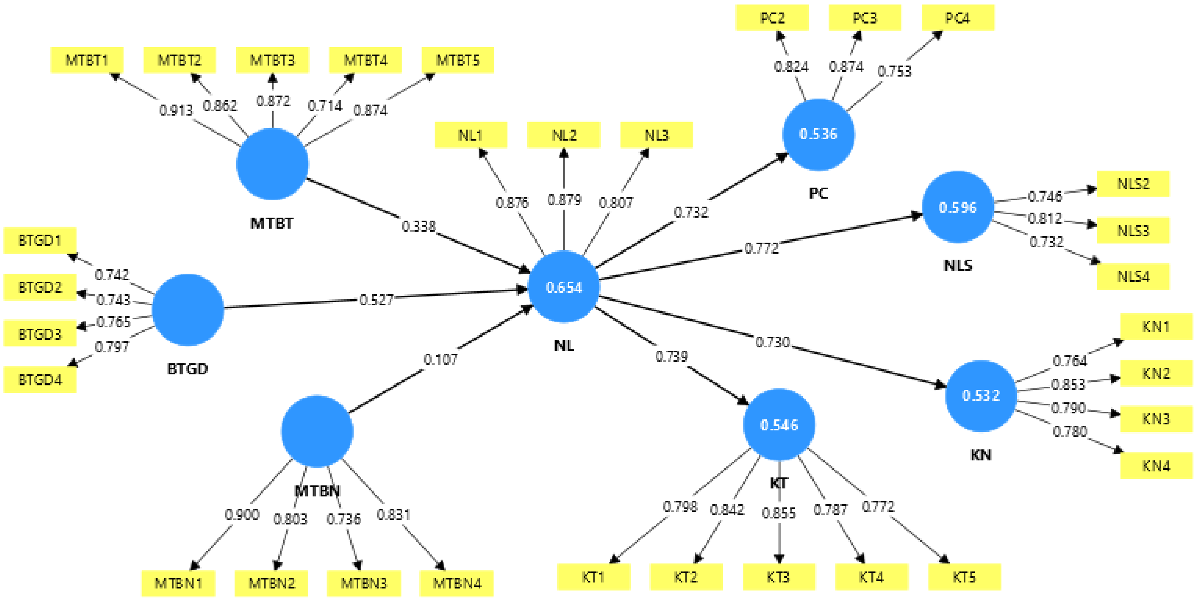
Source: Authors' data analysis

Table 7. *Hypothesis testing results*

Hypothesis	Relationship	Original sample (O)	Sample mean (M)	Std. deviation	t-statistic	p-value	Conclusion
H1	BTGD -> NL	0.527	0.529	0.051	10.391	0.000	Supported
H2	MTBN -> NL	0.107	0.109	0.049	2.198	0.028	Supported
H3	MTBT -> NL	0.338	0.335	0.055	6.147	0.000	Supported

Source: Authors' data analysis

Figure 1. *PLS-SEM structural model results*



Source: Authors' data analysis

Hypothesis testing

Bootstrapping results show that all three hypotheses are supported at the 5% significance level. Director-related factors have the strongest effect ($\beta = 0.527$; $p < 0.001$), followed by the external environment ($\beta = 0.338$; $p < 0.001$), while the internal environment has a smaller but significant effect ($\beta = 0.107$; $p = 0.028$).

Components of leadership competency

All four competency components are strongly and significantly related to overall leadership competency ($p < 0.001$). Digital competency has the strongest association ($\beta = 0.772$), followed by leadership skills ($\beta = 0.739$), leadership traits ($\beta = 0.732$), and leadership knowledge ($\beta = 0.730$).

Table 9. *Relationships between overall leadership competency and its components*

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
NL -> KN	0.730	0.730	0.039	18.847	0.000
NL -> KT	0.739	0.739	0.037	20.127	0.000
NL -> NLS	0.772	0.772	0.037	20.974	0.000
NL -> PC	0.732	0.733	0.039	18.947	0.000

Source: Authors' data analysis

5. Discussion

The findings indicate that leadership competency among directors of private healthcare facilities in the North Central region is shaped by personal (director-related) factors, external environmental conditions, and internal organizational conditions, with director-related factors playing the dominant role.

In provinces with stronger private healthcare development (e.g., Thanh Hoa and Nghe An), leadership tends to be person-centered: directors' strategic vision, decision-making, and resource mobilization capability directly influence investment scale, service orientation, and competitiveness. The 2023 law increases governance requirements, making adaptive leadership even more critical.

In provinces where private healthcare is less developed (e.g., Ha Tinh and Quang Tri), the external environment – access to capital, land, and local policy support – plays a particularly important role, especially amid rising investment costs and tightening facility standards.

In Thua Thien Hue, where high-quality healthcare human resources and central-level hospitals create professional pressure, digital transformation and quality management become decisive. This explains why digital competency emerges as the most influential component of leadership competency.

Policy implications include shifting toward system-based leadership (standardized processes, delegation, succession planning) in fast-growing provinces; strengthening local policy support and leadership development programs in constrained provinces; and prioritizing quality management and digital transformation in provinces with strong professional ecosystems.

Conclusion

The findings indicate that the leadership competency of directors of private healthcare facilities in Vietnam's North Central region is shaped by three groups of factors: (1) leader-related factors, (2) internal organizational factors and staff-related conditions, and (3) external macro-environmental factors. Among these, leader-related factors exert the strongest influence, followed by the external environment, while the internal environment has a smaller but still statistically significant effect. Analysis of the competency structure further shows that digital competency has the strongest association with overall leadership competency, highlighting the growing importance of digital transformation in healthcare governance and operations. Based on these results, the study recommends designing context-specific leadership development programs tailored to provincial conditions, with priority given to strengthening digital competency, strategic planning, financial management, and quality management. In parallel, improving the policy and business environment – through clearer regulations, better access to resources, and stronger support mechanisms – will be essential to enhance directors' leadership capacity and promote the sustainable development of the private healthcare sector in the North Central region.

At the regional level, tailored leadership development programs for directors of private healthcare facilities are needed, incorporating updated legal requirements and healthcare digital transformation agendas. Overall, leadership competency is multi-dimensional and increasingly depends on digital competency in the current phase of healthcare transformation.

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MESOTHERAPY AS A METHOD OF CORRECTION OF ALOPESIA IN PATIENTS AFTER BARIATRY

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Abstract

This article examines the role of mesotherapy in the treatment of alopecia in patients who have undergone bariatric surgery. The authors conducted a comprehensive multivariate analysis, revealing a significant influence of individual, behavioral, and structural factors on the development and course of alopecia. The study results showed that the nature and severity of hair loss depend on the affected area and the time of symptom onset, emphasizing the need for an individualized approach to both diagnosis and treatment.

The study involved 321 patients, divided into groups based on the frequency of mesotherapy use. It was found that frequent and daily use of the procedure may be associated with an increased incidence and severity of alopecia, especially in androgenic and diffuse alopecia. The article emphasizes the importance of performing invasive procedures according to established protocols, taking into account the individual characteristics of the patient. The authors call for further study of the safe and effective use of mesotherapy, which is especially important for improving the quality of life of patients who have undergone bariatric surgery.

Keywords: *bariatric surgery, mesotherapy, alopecia, hair treatment, prevention*

Introduction

Alopecia is a chronic disease characterized by progressive hair loss of various localizations and degrees. This pathology is widespread worldwide and significantly impacts patients' quality of life, causing psychological discomfort, low self-esteem, and social isolation. The problem of alopecia is particularly relevant in patients who have undergone various types of surgical interventions, such as bariatric surgeries, as after such interventions, there is an increase in the frequency and severity of hair loss manifestations (Ruiz-Tovar J., Oller I., Llavero C., Zubiaga L., Diez M., Arroyo A., Calero A., Calpena R., 2014; Darlenski R., Mihaylova V., Handjieva-Darlenska T., 2022).

In recent years, there has been increased interest in clinical practice in studying the factors influencing the development and course of alopecia, as well as in developing effective preventive and therapeutic approaches. Modern medicine aims to comprehensively treat this condition, including not only medication methods but also procedures that stimulate hair follicle regeneration and nutrition, such as mesotherapy, plasma therapy, and the use of mineral and vitamin complexes (Guo H., Zhu J., Ma Y., Sachin B., Cao D., Tang L., 2017; Ledoux S., Flamant M., Calabrese D., Bogard C., Sami O., Coupaye M., 2020).

Today, the development of the field of trichology is accompanied by the introduction of innovative diagnostic methods such as trichoscopy, digital phototrichography, and genetic research, which allows for a more accurate determination of the types and stages of alopecia, as well as the identification of its pathogenetic mechanisms. In the field of treatment, there is a trend towards an individualized approach based on a comprehensive assessment of risk factors, including nutritionological, hormonal, and immunological aspects (El Sayed M. H., Abdallah M. A., Aly D. G., Khater N. H., 2016).

The integration of minimally invasive procedures, such as mesotherapy and plasma therapy, aimed at stimulating hair growth, improving microcirculation, and metabolic processes in the scalp, has become an important trend. At the same time, the issues of safety and effectiveness of these methods remain relevant, especially with long-term use and the presence of associated risk factors, such as previous surgical interventions and microelement deficiencies (Ruiz-Tovar J., Oller I., Llavero C., Zubiaga L., Diez M., Arroyo A., Calero A., Calpena R., 2014; Darlenski R., Mihaylova V., Handjieva-Darlenska T., 2022).

Despite the richness of modern methods for diagnosing and treating alopecia, numerous unresolved issues remain in clinical practice, especially regarding the prevention and selection of optimal methods for correcting the disease in patients after bariatric interventions. In particular, the role of factors such as the characteristics of patients' behavior, the use of mesotherapy, and its influence on the course of the pathology and (Guo H., Zhu J., Ma Y., Sachin B., Cao D., Tang L., 2017; Ledoux S., Flamant M., Calabrese D., Bogard C., Sami O., Coupaye M., 2020) remains insufficiently studied.

The relevance of this study is due to the need to identify and analyze modern approaches, risk factors, and practical aspects of treating alopecia in patients after bariatric surgeries. Conducting such studies will help to form more accurate recommendations and increase the effectiveness of preventive measures, which is especially important in the context of increasing the volume of surgical interventions and the growing number of patients suffering from hair loss. Additionally, the results of this work will expand theoretical knowledge and contribute to the development of clinical trichology, ensuring more quality and personalized treatment of such patients.

Materials and methods

Analysis of alopecia after surgery was performed depending on the mesotherapy. The study involved 321 patients, who were divided into three groups according to the characteristics being studied. The first group included 115 patients suffering from alopecia after bariatric surgery, which made it possible to assess the influence of this type of surgical intervention on the development and nature of alopecia. The third, control group, consisted of 97 individuals without alopecia symptoms after bariatric surgery. The second group included 109 patients with alopecia who had not undergone bariatric surgery, which made it possible to compare the features of the pathology in the context of other possible causes of alopecia. Before starting the study, all participants signed informed consent in accordance with ethical standards. The subject of analysis was clinical and demographic indicators, as well as the features of alopecia course depending on the presence or absence of bariatric surgery.

Statistical analysis was conducted using Stat Tech version 4.12.1. Quantitative indicators were assessed for compliance with the normal distribution using the Shapiro-Wilk criterion (if the sample was less than 50) or the Kolmogorov-Smirnov criterion (if the sample was more than 50). In the absence of a normal distribution, the quantitative data were represented by the median (Me) and the interquartile range (Q1-Q3).

To describe categorical data, absolute values and percentages were used, with 95% confidence intervals for shares calculated using the Klopper-Pearson method. Comparison of three or more groups for quantitative indicators not subject to normal distribution was carried out using the Kraskel-Wallis criterion. Posterior comparisons were carried out using the Dunn criterion with a Holm correction.

Pearson's chi square criterion was used to compare fractions in multi-field conjugate tables. In the case of multiple comparisons, the posteriori analyses were also conducted using the Pirson chi-square criterion with a Holm correction. Statistical significance was established at a level of $p < 0.05$.

Research results

Analysis of the obtained data shows clear differences in the manifestation and degree of alopecia in patients after surgery, depending on the mesotherapy regimen. In the group without mesotherapy, practically all patients had no or minimal alopecia, which confirms the effectiveness of this procedure in preventing or slowing down the progression of hair loss. At the same time, in patients who received mesotherapy occasionally or daily according to doctor's instructions, the frequency and severity of alopecia, especially in more severe forms and affected areas, increased significantly.

Statistical analysis showed that with frequent or daily mesotherapy, the likelihood of alopecia development increases. Especially noticeable is the increase in the number of cases of diffuse and androgenic alopecia in patients receiving procedures according to doctor's prescriptions. In particular, significant differences were noted in the degree of manifestation according to the classification of Sinkler syndrome and the area of damage. The benefits of mesotherapy are contradictory and require more precise study, since, according to the data obtained, if incorrectly applied, it can intensify or accelerate the manifestation of alopecia.

Table 1. *Analysis of postoperative alopecia depending on mesotherapy*

Indicators	Sections	Mesotherapy			P.
		No.	Sometimes	Daily according to the doctor's instructions	
Type of alopecia after surgery	No	163 (98.8)	61 (73.5)	90 (49.2)	< 0.001* $p_{\text{no – daily according to the doctor's instructions}} < 0.001$ $p_{\text{sometimes – daily according to the doctor's instructions}} = 0.004$
	focal A	0 (0.0)	0 (0.0)	1 (0.5)	
	androgenic A	2 (1.2)	11 (13.3)	58 (31.7)	
	diffuse A	0 (0.0)	11 (13.3)	34 (18.6)	
Alopecia degree according to Sinclair classification	0	162 (98.2)	61 (73.5)	90 (49.2)	< 0.001* $p_{\text{no – sometimes}} < 0.001$ $p_{\text{no – daily according to the doctor's instructions}} < 0.001$ $p_{\text{sometimes – daily according to the doctor's instructions}} = 0.013$
	I	1 (0.6)	4 (4,8)	20 (10.9)	
	II	0 (0.0)	5 (6.0)	19 (10.4).	
	III	2 (1.2)	3 (3,6)	18 (9.8)	
	IV	0 (0.0)	6 (7.2)	18 (9.8)	
	V	0 (0.0)	4 (4,8)	18 (9.8)	
Area of damage	No	163 (98.8)	61 (73.5)	92 (50.5)	< 0.001* $p_{\text{no – daily according to the doctor's instructions}} < 0.001$ $p_{\text{sometimes – daily according to the doctor's instructions}} = 0.042$
	temporal region	1 (0.6)	3 (3,6)	12 (6.6)	
	parietal region	0 (0.0)	4 (4,8)	24 (13.2)	
	occipital region	0 (0.0)	3 (3,6)	14 (7.7)	
	more than one area	1 (0.6)	12 (14.5)	39 (21.4)	
	total defeat	0 (0.0)	0 (0.0)	1 (0.5)	

** – differences in indicators are statistically significant ($p < 0.05$)*

Theoretically, the development of alopecia with frequent or daily mesotherapy can be attributed to a number of factors. For example, many injections, the use of certain medicines or ingredients, incorrect technique, or the body's individual reaction can cause inflammation, skin damage, and follicles, leading to increased hair loss. At the same time, with proper therapy and drug selection, mesotherapy can have a beneficial effect by stimulating blood circulation and metabolic processes, improving hair follicle nutrition.

In interpreting the results, it is important to note that mesotherapy, being an invasive procedure, must be carried out strictly according to protocols, while it is important to consider the individual characteristics of the patient. Otherwise, repeated injections and technical violations can contribute to the development of inflammatory processes, deterioration of microcirculation, and consequently, accelerated progression of alopecia.

Conclusion

Thus, for the prevention and treatment of alopecia in patients after surgery, strict criteria for prescribing mesotherapy, individual selection of medications, and control over the technique of procedures are necessary. Overall, these results highlight the need for further research and clarification of the conditions for safe and effective use of mesotherapy in this group of patients.

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Section 5. Technical sciences in general

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REGENERATION OF PROCESS WATER IN SMART TEXTILE MANUFACTURING. (Regeneration of process water in smart textile manufacturing without the use of chemical reagents)

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Abstract

This paper outlines a structured technological framework for water treatment and regeneration within smart home infrastructure, designed to ensure the delivery of water at the required consumption level in compliance with applicable quality standards. The proposed system is based on established experience in electrochemical water treatment and integrates aerodynamic and electrochemical processing modules.

Keywords: *Integrated water treatment systems; Integrated aqueous solution treatment systems; Base industrial modules; Capacity of a base industrial module; Operational performance of a single base module; Minimum capacity of a base industrial module; System – modular complex*

For water supplied to the smart home distribution system from linear (centralized) sources, preliminary treatment is performed using aerodynamic foam generators. These units separate organic contaminants while simultaneously dissolving atmospheric oxygen into the water, achieving oxygen saturation levels of up to 96%, as confirmed by laboratory testing conducted in leading research facilities.

For independently located smart homes supplied by artesian wells, inlet treatment is additionally carried out through electrochemical cells integrated into an electrochemical reactor. The system enables the following operations:

- desalination via accelerated electrolytic salt deposition onto a movable cathode manufactured from carbon–carbon composite fabric;
- pH adjustment to neutral levels;
- controlled dosing of coagulants to facilitate sediment formation and subsequent separation of precipitates from purified water;
- aeration through aerodynamic foam generators.

Where required, water disinfection is achieved through sequential pH modulation, involving temporary acidification followed by restoration to neutral pH.

For treated wastewater, the same electrochemical processing system enables removal of contaminants introduced during use. The purified fraction of the water stream can then be activated for recirculation within the smart home system, while the remaining treated water may be directed for irrigation purposes.

The proposed integrated approach supports resource efficiency, water reuse, and compliance with modern environmental and quality standards within intelligent residential infrastructure systems.

Applications of Water Treatment Technologies

Classification of Integrated Water and Aqueous Solution Treatment Systems

Integrated industrial systems for the treatment of water and aqueous solutions are designed with a modular structure.

The minimum capacity of one base industrial module equipped with a single two-section ion-exchange column is 500 liters per hour.

Figure 1.

The operational performance of one base module equipped with two two-section ion-exchange columns is 1,000 liters per hour. The minimum capacity of one base industrial module equipped with a single three-section ion-exchange column is 750 liters per hour. The operational performance of one base module equipped with two three-section ion-exchange columns is 1,500 liters per hour. For all specified systems, ion-exchange treatment columns are designed in a two-section configuration. Where increased system capacity is required, a modular complex configuration is implemented using three-section ion-exchange columns.

A brief description of the technologies of electrochemical treatment of water:

1. Technology of water treatment from radioactive pollution

The technology represents a combination of consecutive stages of electrochemical and biological treatment. Electrochemical treatment, taking into account the properties of water contaminated with radioactive isotopes, is based on two stages of treatment, -the impact on the volume of water through aerodynamic pulsation of compressed gas from a compartment of the purified volume of water, foam consisting of organic substances and other contaminants with a low level of conductivity, after which the impact on the stream of water, through the help of neutral electrodes, made from carbon composite materials, and stimulation of the formation in the stream of water, of oxides of radioactive materials contained in it, with a subsequent separation of the specified oxides from the stream of water.

The biological treatment is based on the principle of absorption of crushed particles of algae (for example the algae type «Ozolla»), ions of radioactive isotopes, contained in the water. The proposed technological scheme of treatment can reduce the concentration of radioactive contamination to a level of one trillionth of a gram, which exceeds the requirements of existing standards.

2. Technology of desalting seawater, based on the method and technology of accelerated electrochemical processes

The technology represents the process of electrolytic sedimentation of salt on a constantly running infinite conveyer (cathode) from coal composite fabric. Sea water is moved on special insoluble anodes, which direct it to the surface of the cathode-conveyor. With this the sea water is regarded as an electrolyte with a salt content of 35–42 grams per liter. At such a sodium content of salt sedimentation, at the delivery into the zone of treatment of an electrical current with a density of 35–50 amperes per one square of decimeter electrodes, it is enabled to achieve a rather high speed of sedimentation, in order to ensure efficient expediency of the project. Installations should have a modular principle of design.

The prospective efficient productivity of such a module is 50 cubic meters per hour.

The specified modules can be used as means of preliminary treatment of seawater before the installation of reverse osmosis, for increasing the service life of membranes, or as autonomous complexes for desalination.

3. Technology for the reduction in water of the concentration of salt hardness.

The technology is based on the principle of consecutive electrochemical changes of the level of acidity and alkalinity in a stream of water, separation of the resulting sediment and final adjustment of the specified level depending on the end user of the water. The water treatment is expected in electrochemical reactors with various types of electrodes and electrode cartridges, changes of types and materials of electrodes which can change depending on the type of hardness salts, their concentration, and end-user requirements. As the finishing stage of treatment, the application of ultra-filtration or other equivalent membrane technology is presumed. The proposed technological complex of special equipment can also include flotation modules, aeration units, and different kinds of filtration. After treatment in electrochemical reactors for more deep cleaning of water from hardness salts, there need to be used special column-modules with capsules, filled with natural coarse-grained zeolite, previously heat-treated in a special way.

4. Technology for adjusting the level of acidity or alkalinity in water or aqueous solutions;

The technology is based on the oxidation of water in an ascending flow in the electrode cell with neutral electrodes, separated by a permeable membrane from polypropylene fabric; the electrodes are insoluble; variations of electrode materials and coating material on the electrode surface are possible. On the basis of the indicated technology it is possible to present the design of the original technological equipment, while it is also possible to present a version of the integrated system in which are combined electrocoagulation and adjustment of acidity or alkalinity, and in this case, the electrode cell anodes must be soluble; technological speculations have been tested on electrode cells with polarizable and selectively soluble electrodes, the results of the tests were positive, and it is supposed, that for the first time the effect of the correction of acidity and alkalinity is achieved with the use of polarizable electrodes;

5. Technology of electrochemical disinfection of water or aqueous solutions;

The technology is based on the insertion into an ascending flow of water or aqueous solution, of current impulses of high density combined with the initiation of a regional effect of electrodes on the input and output of the inter-electrode space; a technique which is frequently tested on insoluble electrodes; The proposed progress of the technology, allows the application of new composite materials and new configurations of electrochemical cells for disinfection; on the basis of this idea is a conceptual design of original technological equipment, according to preliminary estimates, having a necessary level of novelty, non-obviousness, and utility; as the prototype of the indicated technology and equipment, can be used a previous patent application;

6. Technology for the decontamination of surfaces by means of a combination of water flow charged with positive and negative electrical potential

The technology is based on the properties and possibilities of the electrochemical reactors in the division of the fluid flow of the aqueous solution or water into two streams with different levels of acidity or alkalinity and accordingly charged positive and negative electrical potentials from the anode and the cathode.

The technology is based on the oxidation of water in an ascending flow in an electrode cell of an electrochemical reactor with neutral electrodes, divided by a permeable membrane from polypropylene fabric; the electrodes are insoluble; variations of electrode materials and special coatings of the working surface of the electrodes in cases of particular necessity for the quality of deactivating the liquid for chemical purity are possible.

After the division of both flows using the original injector are released into one point of the surface, and neutralize the static electricity at this point and simultaneously deactivate the surface at this point, and, during scanning of the surface, the neutralization of the static electricity on all the scanned surface occurs, and, accordingly, so does the decontamination of the entire surface.

7. Technologies of neutralization of static electricity on the surface by means of a connection on the surface of the flows of water, charged with positive and negative electrical potentials.

The technology is based on the properties and possibilities of the electrochemical reactors in the division of the fluid flow of the aqueous solution or water into two streams with different levels of acidity or alkalinity;

The technology is based on the oxidation of water in an ascending flow in the electrode cell with neutral electrodes, separated by a permeable membrane from polypropylene fabric; the electrodes are insoluble; variations of electrode materials and coating material on the electrode surface are possible.

After the division of both flows using the original injector are released into one point of the surface, and neutralize the static electricity at this point, and at the scanning of the surface there occurs a neutralization of the static electricity on all the scanned surface.

8. Technologies of electrocoagulation by means of coaxial electrochemical reactors

The technology is actualized by means of an electrochemical reactor with coaxial tubular electrodes; such a reactor differs by having extremely small dimensions in relation to the volume of the treatable liquid.

Otherwise, the principle of operation of the electrochemical reactor is analogous to conventional reactors, developed by the company and possesses the same technological and operational advantages.

The main operational advantage of this technology is the possibility during the work process of such a reactor to carry out the regulation of the reciprocal position of the cathode and anode without stopping the process of coagulation.

9. Technologies of electrochemical treatment of water and other liquids using electrochemical reactors with elastic, polarizable tape electrodes

The technology is realized in an electrochemical reactor that incorporates flexible porous strip electrodes, made of composite carbon fabric.

Such electrodes are extremely chemically stable and such a process of treatment does not bring into the treatable water any products of the destruction of the electrodes.

Such a process is precise and has a maximally low rate of collateral contaminants, which provides it a high efficiency in the process with full regeneration and recirculation of working solutions and technological liquids.

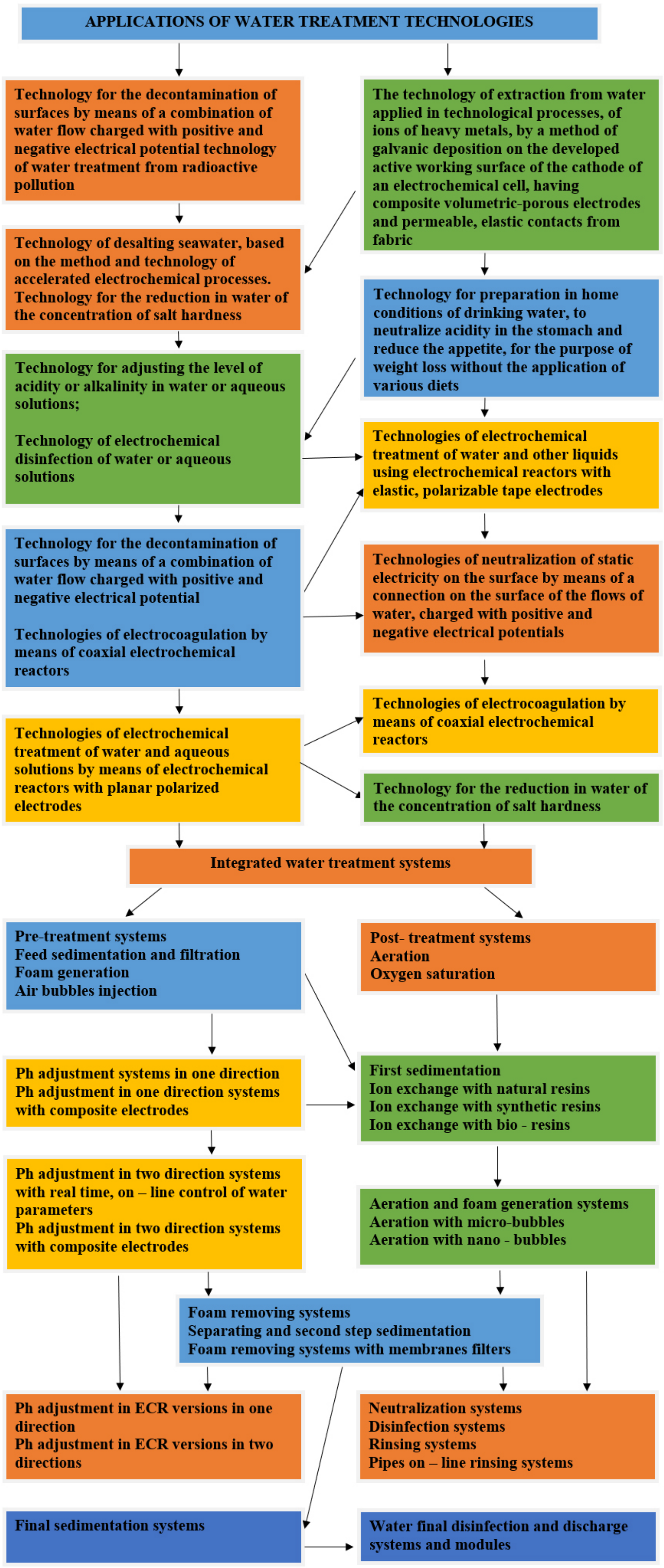
10. Technologies of electrochemical treatment of water and aqueous solutions by means of electrochemical reactors with planar polarized electrodes;

The combination of the factor of the application of planar polarizable electrodes with the execution of the specified electrodes from carbon composite materials gives, in comparison with traditionally known designs of electrochemical reactors with typical electrodes, a tangible economical and qualitative effect.

11. Technology for preparation in home conditions of drinking water, to neutralize acidity in the stomach and reduce the appetite, for the purpose of weight loss without the application of various diets

The technology is based on the possibility of increasing the level of alkalinity of drinking water by electrochemical influence, without applying any chemical reagents; the device is connected to the water supply system, has its own portable power source; the electrodes can be made of various materials, composites, and from titanium coated with ruthenium oxide; productivity is 10 liters per hour; possibilities to reduce the appetite by means of partial neutralization of the gastric juice were discussed with experts in alternative medicine and received unequivocal approval; there is a conceptual design of the device for home usage, which in combination with technological use, on a preliminary assessment, possesses intrinsic novelty, a non-obvious technical solution, and usefulness;

Figure 2.


APPLICATIONS OF WATER TREATMENT TECHNOLOGIES
Technology for the decontamination of surfaces by means of a combination of water flow charged with positive and negative electrical potential technology of water treatment from radioactive pollution
The technology of extraction from water applied in technological processes, of ions of heavy metals, by a method of galvanic deposition on the developed active working surface of the cathode of an electrochemical cell, having composite volumetric-porous electrodes and permeable, elastic contacts from fabric
Technology of desalting seawater, based on the method and technology of accelerated electrochemical processes. Technology for the reduction in water of the concentration of salt hardness
Technology for preparation in home conditions of drinking water, to neutralize acidity in the stomach and reduce the appetite, for the purpose of weight loss without the application of various diets
Technology for adjusting the level of acidity or alkalinity in water or aqueous solutions;
Technology of electrochemical disinfection of water or aqueous solutions
Technologies of electrochemical treatment of water and other liquids using electrochemical reactors with elastic, polarizable tape electrodes
Technology for the decontamination of surfaces by means of a combination of water flow charged with positive and negative electrical potential
Technologies of electrocoagulation by means of coaxial electrochemical reactors
Technologies of neutralization of static electricity on the surface by means of a connection on the surface of the flows of water, charged with positive and negative electrical potentials
Technologies of electrochemical treatment of water and aqueous solutions by means of electrochemical reactors with planar polarized electrodes
Technologies of electrocoagulation by means of coaxial electrochemical reactors
Technology for the reduction in water of the concentration of salt hardness
Integrated water treatment systems
Pre-treatment systems
Feed sedimentation and filtration
Foam generation
Air bubbles injection
Post- treatment systems
Aeration
Oxygen saturation
Ph adjustment systems in one direction
Ph adjustment in one direction systems with composite electrodes
First sedimentation
Ion exchange with natural resins
Ion exchange with synthetic resins
Ion exchange with bio - resins
Ph adjustment in two direction systems with real time, on – line control of water parameters
Ph adjustment in two direction systems with composite electrodes
Aeration and foam generation systems
Aeration with micro-bubbles
Aeration with nano - bubbles
Foam removing systems
Separating and second step sedimentation
Foam removing systems with membranes filters
Ph adjustment in ECR versions in one direction
Ph adjustment in ECR versions in two directions
Neutralization systems
Disinfection systems
Rinsing systems
Pipes on – line rinsing systems
Final sedimentation systems
Water final disinfection and discharge systems and modules

12. The technology of extraction from water applied in technological processes, of ions of heavy metals, by a method of galvanic deposition on the developed active working surface of the cathode of an electrochemical cell, having composite volumetric-porous electrodes and permeable, elastic contacts from carbon-carbon composite fabric

The effect of the technology is achieved and ensured due to a roughly 100,000 times more advanced contact surface in both electrodes. This, in turn, provides significantly greater exchange capacity of the cathode and the possibility for the apparatus to work longer without replacing the electrodes, and without stopping the production line.

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COMPOSITE FOOD PRODUCTS AS A RESULT OF AN INTEGRATIVE PROCESS. (Composite Smart Dairy Food Products as a Result of an Integrative Innovative Technological Process Incorporating Elements of Artificial Intelligence and Artificial Neural Networks)

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Abstract

The text examines the widespread misconception regarding the harmful effects of butter due to its cholesterol content. It emphasizes that cholesterol itself is essential for the human body, while the actual risk arises from metabolic disorders leading to its excessive accumulation in blood vessels. It is noted that moderate consumption of butter (up to 10 g per day) does not pose health risks to healthy individuals and may have beneficial effects on vision, skin, hair, bone, and muscle tissue due to its content of fatty acids, vitamins, calcium, phospholipids, and essential amino acids. Particular attention is given to the fact that a significant proportion of nutrients is destroyed during heat treatment; therefore, butter is recommended to be consumed in its natural form, added to prepared dishes. The conclusion highlights the safety and benefits of moderate butter consumption within the framework of a balanced diet.

Keywords: *Composite products; Composite food products; Integrative innovative technological process; Cholesterol; Regulatory standards requirements; Permissible caloric intake; Beneficial unsaturated fatty acids; Essential amino acids; Innovative practice*

Criteria and Methods for Achieving the Ideal Final Result in the Innovative Modification and Optimization of Large-Scale Continuous Automated Production Complexes in the Dairy Industry Utilizing Artificial Intelligence and Artificial Neural Networks in Control and Monitoring Systems

The author of the present publication notes that among the first to formulate the task of achieving the Ideal Final Result (IFR), in accordance with the updated and modified 40 Inventive Principles, as well as with the methods and tools of TRIZ (Theory of Inventive Problem Solving) and ARIZ (Algorithm of Inventive Problem Solving), were prominent innovation specialists and technologists of modern dairy enterprises.

According to their conceptual methodology, the application of criteria and methods for achieving the Ideal Final Result in the comprehensive evaluation of innovative solutions yields exceptionally high levels of effectiveness and accuracy. When combined with other analytical approaches, this framework significantly increases the proportion of successful startups and, consequently, substantially enhances the efficiency of implementing new digital technologies within large-scale automated dairy production systems.

Figures 1, 2, 3

1)

2)

3)

Figures 1, 2, and 3 present photographs of state-of-the-art technological equipment used in the production of high-quality dairy products that fully comply with the stringent requirements of current regulatory standards

At present, the development trajectory of innovative technologies also encompasses the production of so-called smart food products. In this context, the manufacturing of composite food products is advancing through the active integration of artificial intelligence (AI) and artificial neural networks (ANNs) into control and monitoring systems. In the near future, such production systems are expected to transition toward the use of quantum computing technologies and various processor modules developed on their basis.

Innovative practice has demonstrated that this level of integrated system architecture significantly increases the accuracy and speed of control and management processes. These processes are built upon the principles of electromagnetic resonance spectroscopy and incorporate flexible analytical processing of measurement results, again utilizing elements of artificial intelligence and artificial neural networks to enhance precision, adaptability, and overall operational efficiency.

Figure 4.

Figure 4 presents one of the modules of this technological equipment, characterized by an exceptionally high density of component integration and assembly.

Figure 5.

Figure 5 illustrates the types and variants of composite dairy products.

Composite Dairy Food Products as a Result of an Integrative Innovative Technological Process

A widespread misconception suggests that butter is harmful due to its high cholesterol content. However, cholesterol itself is not inherently dangerous; on the contrary, it is essential for the human body. The actual health risk arises from metabolic disorders that lead to excessive cholesterol accumulation on blood vessel walls.

The consumption of butter, when moderate, does not cause such severe consequences. It is beneficial for vision; ophthalmologists often refer to it as contributing to the preservation of ocular youthfulness. Butter contains fatty acids and numerous vitamins that support overall physiological functions.

Nutritionists recommend that healthy individuals consume up to 10 grams of fresh butter per day, which falls within acceptable caloric intake limits. Butter should preferably be consumed in its natural form, as heat treatment results in the loss of more than 50% of its nutrients, the destruction of vitamins, and the conversion of beneficial unsaturated fatty acids into less desirable saturated forms.

Butter is not only nutritious but also beneficial for the skin, hair, vision, bone, and muscle tissue. It is rich in vitamins and calcium, and it contains phospholipids necessary for cellular structure, particularly nerve cells. In addition, butter includes essential amino acids required for normal physiological functioning, which must be obtained from dietary sources. Therefore, the beneficial properties of butter are well substantiated. It should be noted, however, that melting butter during frying significantly reduces its vitamin content; thus, it is preferable to add butter to prepared dishes.

Although butter contains cholesterol, it becomes potentially harmful only when fatty foods are consumed excessively. In moderate amounts, cholesterol is necessary, as it participates in the formation of vascular cell membranes. Accordingly, one or two slices of bread with fresh butter per day are unlikely to pose any health risk.

Twenty Fundamental Principles and Characteristics Explaining the Unique Properties of Butter

1. Butter is rich in the most bioavailable form of vitamin A, essential for the proper functioning of the thyroid and adrenal glands.
2. Butter contains lauric acid, which is important for infection prevention and the development of biological defense mechanisms.
3. Butter contains lecithin, which supports the stabilization of cholesterol metabolism.
4. Butter contains antioxidants that protect the body from oxidative stress and free radical damage.
5. Butter's antioxidant components help protect the circulatory system from weakening and thinning of arterial walls.
6. Butter is an important source of vitamins E and K.
7. Butter is a rich biological source of selenium, a vital trace mineral.

8. The saturated animal fats in butter may exhibit properties that help inhibit the development of certain tumors.
9. Butter contains amino acids that may support muscle development and immune function.
10. Vitamin D found in butter plays a significant role in calcium absorption.
11. Butter contributes to the protection of dental enamel.
12. Butter contains factors that may help protect joints from stiffness.
13. The fatty acids in butter may help prevent arterial calcification.
14. Butter is a source of “Activator X” (often associated with vitamin K2), which supports the absorption of beneficial micronutrients.
15. Butter contains iodine in a highly absorbable form.
16. Butter may support reproductive health in women.
17. Butter serves as a rapid source of energy.
18. The cholesterol present in dairy fat plays an important role in the development of the brain and nervous system in children.
19. Butter contains arachidonic acid (AA), which plays an important role in brain function and cellular structure.
20. Butter may provide protective effects against gastrointestinal infections, particularly in early childhood and old age.

If needed, I can further adapt this text into a formal scientific article format with structured sections (Introduction, Materials and Methods, Results, Conclusion) or align it with academic publication standards.

Figure 6.

Companies–developers propose an integrated group technology for the production of ultra-pure food composites for the following product categories:

- **Homogenized Meta-Pure Food Composition – Cream**
- **Homogenized Meta-Pure Food Composition – Butter**

Depending on the selected market entry strategy and product positioning, innovative companies hold patent ownership rights and may grant licenses for the use of the following universal technologies, including nano-technologies:

- **Active non-contact real-time online monitoring technology** for determining the composition and concentration of components in liquids, including cow’s milk, with the capability of controlling somatic cell count and more than twenty additional key components and quality parameters of raw milk;
- **Reagent-free cleaning, sterilization, and disinfection technology** for technological pipelines and process tanks in dairy production lines;
- **Three-dimensional dynamic homogeneous fermentation technology** for dairy products;
- **Vortex micro-aeration technology** for dairy matrices;
- **Hydrodynamic harmonic pulsating shock kinetic impact technology** applied to liquid volumes (including milk, cream, and sour cream).

A special role in this process is played by innovative concepts and enabling technologies. Food products, similarly to pharmaceutical preparations and, to a certain extent, cosmetic products, constitute a strictly quality-controlled sector within the innovative technological landscape.

This sector is primarily characterized by the mandatory full compliance of new innovative products and technologies with public health standards and increasingly stringent environmental regulations.

It must also be acknowledged that this technological field is significantly influenced by established traditions, as well as climatic and cultural characteristics specific to the region in which the innovative product is introduced to consumers.

At the same time, it is important to recognize that the most successful local innovative solutions and inventions – especially those applicable not only within the limited scope of food production but also across broader technological domains – can serve as effective driving forces in the progressive development of integrative innovative technologies.

Figure 7.

New Technology of Hydrodynamic Mixing of Various Liquid Components with Simultaneous Whipping in a Dynamic, Periodically Repeating, Developed Kinetic Regime with Regeneration of Accumulated Kinetic Energy and Its Sequential Transfer into the Process

Figure 8.

The proposed innovative technology represents a process of dynamic impact on liquid or semi-consistent components being mixed and whipped.

The most extensively studied and frequently applied components within this process, in various configurations, are derived from dairy products.

Рисунки 9, 10, 11, 12, 13;

The developing company is conducting research and development activities aimed at designing specialized technological equipment to implement this process. The objective of these research, engineering, and industrial design efforts – along with the development of dietetic algorithms and process control programs – is to identify new approaches to the production of composite, compounded, or homogeneously integrated food products characterized by reduced or minimized fat content and, conversely, increased concentrations of vitamins and biologically active elements.

An additional objective of the proposed process is to enable, without thermal treatment or other conventional product-altering methods, the formation of mixtures or whipped composite systems – primarily dairy or fermented dairy-based – which under standard conditions would either not mix at all, mix poorly, or form unstable emulsions or suspensions.

This technology therefore aims to create stable, structurally integrated food systems through controlled hydrodynamic kinetic activation rather than through heat-based processing or chemical modification.

Образцы композитных продуктов.

Appendix 1.

There are 20 basic principles and features that reveal and explain the unique properties of butter:

1. Butter is rich in the most easily absorbed form of vitamin A by the body necessary for normal functioning of the thyroid and adrenal glands
2. Butter Contains laurel acid (lauric), the presence of which is extremely important in terms of prevention and the prevention of infections and the accumulation of biological mechanisms of resistance to infection
3. Butter contains lecithin, the basis for the stabilization of the biological mechanism for the formation of cholesterol metabolism.
4. Butter contains antioxidants that protect the body from the spontaneous and radical biological degradation
5. Butter has in its composition of antioxidants that protect the body's circulatory system from weakening and thinning of the walls of the arteries.
6. Butter is an important and effective source of extremely useful vitamins E and K.
7. Butter is a very rich and unique biological sources vital for the body's mineral selenium.
8. Saturated animal fats in butter have strong influence on the properties to prevent the formation of a variety of tumors and cancer.
9. butter contains amino acids, which are a powerful agent prevents the formation of cancerous tumors, stimulates the development of muscles and stimulating factor for the restoration of immunity and inviolability.
10. Vitamin D is found in the oil significantly affects the absorption of calcium.
11. Butter protects against decay of the tooth enamel.
12. Butter is the only source factor that protects against hardening of the joints.
13. Factor presence of fatty acids in butter also prevents calcification of the arteries, streams, and hardening of glands.
14. Butter is a source of Activator X, which helps your body absorb the beneficial minerals.
15. Butter contains iodine very absorbed form.
16. Butter can promote reproductive functions in the body in women.
17. Butter is a source of quick energy.
18. Positive Cholesterol that soldierships in milk fat lochan important for the development of a child's brain and nervous system development.
19. Butter Containing Arachidonic acid (AA), which plays an important role in brain function, and is a vital component of cells.
20. Butter protects the body from the gastrointestinal infections in the very young or the elderly

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RESEARCH OF THE ADSORPTION MECHANISMS FOR PURIFYING USED MOTOR OILS

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Abstract

This article analyses the changes in the physicochemical properties of used oils that occur following an adsorption purification process using bentonite. According to the research results, the bleaching clay and bentonite adsorbent effectively absorbs mechanical impurities, oxidation products, and harmful additives from the oil composition. After the purification process, the oil's color lightens, its acidity decreases, and its potential for reuse increases. The results indicate that purifying oils with bleaching clay and bentonite is an environmentally and economically effective method.

Keywords: *adsorption, used engine oil, regeneration, adsorbent, recycling, bentonite*

Introduction

Engine oils, which are widely used in the automotive and industrial sectors today, are an important material that ensures the continuous operation of machinery and mechanisms. However, during use, the physicochemical properties of the oils deteriorate, and they accumulate oxidation products, resins, metal particles, fuel residues and water. This makes it impossible for the oils to be used further and leads to their collection as waste. According to statistics, millions of tons of used engine oils are disposed of worldwide each year, and they are classified as hazardous waste that pollutes the environment.

Therefore, the recycling and regeneration of used oil is a pressing scientific and technical issue. Among the regeneration methods, adsorption stands out for its simplicity and efficiency.

In the last decade, solvent extraction-adsorption has been studied for base oil recovery from SEO due to the benefits accruing to the treatment method. A single solvent, methyl ethyl ketone (MEK) followed by clay has been studied. The method was compared with acid/clay- percolation processes. The latter gave a low yield of base oil. Thus, considering the sludge generated from the acid treatment, solvent/clay treatment remains the most preferred method. The removal of PAHs by solid surfaces from used oil using solvent (1-butanol) extraction and adsorption (activated carbon) was studied, which exhibited a potential adherence of PAHs on its surface than other adsorbent tested. Other studies gave similar results. Comparison of a composite solvent, single solvent, and acid treatment methods on SEO has been studied. The best method that gave good quality base oil was composite solvent- extraction (Filho et al., 2010).

The adsorption process in SEO treatment helps to remove pollutants, especially PAHs, heavy metals, and color in SEO by trapping them on the active sites of the adsorbent. Solvent extraction is capable of removing about 10–14% of impurities in SEO which is mainly the sludge, but the base oil still contains some impurities such as PAHs and heavy metals. Thus, the adsorption process plays a good role in the removal of the remaining impurities. Carbon and clay are good adsorbents for this purpose because of their high porosity and surface area. Lignocellulosic agricultural wastes have high carbon content and low inorganic compounds and are hence, good precursors for AC production. Activated carbon AC prepared from lignocellulosic precursors have been known for the separation of gaseous mixtures, removal of dyes, PAHs and heavy metals from waste oil and water effluent. Also, local clay can be used as adsorbent due to its ability to remove colour and other impurities in oils (Ani et al., 2023).

Materials and Methods

The adsorption method for purifying used motor oils is currently one of the most promising approaches to resolving environmental and economic issues. This method serves to restore the physicochemical properties of engine oils, enabling their reuse and reducing the volume of waste. In the future, the efficiency of the method can be further increased by developing new, high-performance adsorbents and optimizing the technological processes.

Low-rank coal or Brown Coal can be used as an adsorbent by using a combination solution of H_3PO_4–$NaHCO_3$ is 2.5M on chemical activation (Patmawati and Alwathan, 2019). In this study will use the same adsorbent derived from Brown Coal. with a calorific value of 4503 J/g. However, this study will focus on the purification method of pyrolysis –Adsorption, namely base fuel or raw materials which is the result of pyrolysis purified again by pyrolysis and adsorption techniques, as the main test parameter is the yield of the results obtained, then the yield of adsorption results and, or pyrolysis obtained will be measured and calculated, then it will be analyzed density, viscosity, specific gravity, color, yield, and API(API, which is an abbreviation for the American Petroleum Institute, is a standard code that determines oil quality) (Alwathan et al., 2024).

Purifying used motor oil involves removing contaminants like water, fuel, sludge, and metal shavings to restore it for reuse, usually through a combination of settling, filtration, and distillation. Key methods include sedimentation, centrifugation, chemical treatment (e.g., sodium hydroxide), and vacuum distillation to remove impurities, producing base oil or cleaner fuel (Hidaya et al., 2018).

Key Steps in Purifying Used Motor Oil:

- ***Settling & Pretreatment:*** *Allowing the oil to stand for 24–48 hours lets sludge and heavy particles settle to the bottom. Heating to ~650 °F can improve the removal of contaminants;*
- ***Filtration:*** *Passing the oil through filters (cloth, paper, or mechanical filters) removes solid contaminants and debris;*
- ***Dewatering:*** *Removing water content by heating or through specialized separation processes;*
- ***Centrifugation:*** *Using high-G force to separate impurities and water from the oil.*

Chemical/Vacuum Treatment: *Advanced methods like distillation or treatment with sulfuric acid or clay are used to remove fine impurities, improve color, and restore viscosity.*

Safety Precautions:

- *Always perform purification in well-ventilated areas.*
- *Avoid open flames when heating, as it can be a fire hazard.*
- *Dispose of the resulting sludge and waste byproducts at approved hazardous waste centers.*

Results and Discussion

Adsorption is a surface phenomenon whereby particles from a liquid or gas are absorbed onto the surface of a solid substance (adsorbent). The adsorbents used for the purification of motor oils (activated carbon, bentonite, silica gel, zeolite, aluminosilicates) have high porosity and a large surface area. With their help, colorants; tars and oxidation products; organic acids; heavy metals; coke and dispersed particles are effectively removed.

Table 1 presents the technology for purifying used engine oils by adsorption.

Table 1. *Adsorption-based technology for the purification of used engine oils*

Stages	Process Description	Result
1. Preliminary preparation	Large solid particles, sediment, and the liquid phase (water) are separated from the oil using mechanical filters, screens, or by settling	Separation of large particles by filtration. The oil is pre-treated, removing water and mechanical additives.
2. Heating	The oil is heated to 70–100 °C	This step ensures good mixing of the adsorbent with the oil and reduces viscosity.
3. Adsorption process	The oil is mixed with the adsorbent (activated carbon, bentonite, zeolite, silica gel, etc.). Impurities are adsorbed onto the adsorbent surface	Colourants, tars, oxidation products and heavy metals are removed
4. Separation	The adsorbent is separated from the oil by filtration or decantation	The purified oil is recovered
5. Additional processing	Neutralization (with acid/alkali). Additional adsorption for color improvement – Useful additives (inhibitors, detergents/modifiers) are added	Restores the oil's quality and increases its stability.

High purification level (70–85%). Environmentally safe, with low atmospheric emissions. The technology is simple and energy-efficient.

The adsorption method is considered one of the most effective and environmentally safe methods for the regeneration of used motor oils. It is widely used in practice as it can be carried out using inexpensive raw materials and provides a high degree of purification.

Table 2. *Adsorbents used and their properties*

Type of adsorbent	Main properties	Advantages	Disadvantages
Activated carbon	High porosity, large surface area, good adsorption of organic substances	Improves color, effectively removes oxidation products	Expensive, difficult to regenerate
Bleaching clay	Natural clay mineral, with high sorption capacity	Inexpensive, environmentally safe, widely available	Low mechanical strength
Bentonite	Natural clay mineral, with high adsorption capacity	Inexpensive, environmentally safe, widely available	Low mechanical strength
Silica gel	High surface area, effectively adsorbs moisture and acids	Good at removing organic acids and water	Higher price, limited reusability

Type of adsorbent	Main properties	Advantages	Disadvantages
Zeolite	Crystalline aluminosilicate, with ion-exchange capacity	Absorbs heavy metal ions effectively, stable	Complex preparation process
Aluminosilicates	High mechanical stability, adsorbs various particles	Can be reused multiple times	Efficiency is lower than that of activated carbon

From the table, it can be concluded that the most effective adsorbent is activated carbon, since it has a high surface area, while bentonite is the cheapest and most widely available. Zeolite performs best in ion exchange, and moreover, silica gel can be used to dry water that has entered the oil.

The purification process was carried out using the adsorption method. The local bleaching clay was dried, sieved and used as the adsorbent. The used oil was first filtered and then treated with the adsorbent.

Experiments have shown that adsorption purification using local bleaching clay significantly lightened the color of the used oil, allowing it to be cleaned of mechanical impurities, as well as partially of resins and oxidation products. After purification, positive changes were observed in the oil's viscosity, acidity number, and other key physicochemical parameters.

Among adsorbents, bentonite occupies a special position due to its high surface area, swelling properties, and strong adsorption capacity. Bentonite is one of the natural clays, whose main component is the mineral montmorillonite. When it comes into contact with water and oil, it swells and absorbs a large number of particles onto its surface. For this reason, bentonite enables the effective purification of used oils from mechanical particles, resin and oxidation products.

Also, bentonite is a widespread, cheap and environmentally friendly material, so its potential for industrial use is very high.

For more effective oil purification, bentonite was used as an adsorbent. In this case, the used oil was pre-filtered and cleaned of mechanical impurities. Bentonite was dried, crushed, sieved and used as an adsorbent. The adsorption process was carried out for a certain time, and then the purified oil was separated by filtration.

Conclusion

Adsorption treatment using local bleaching clay is an effective method for improving the quality of used oils. The cost-effectiveness, simplicity and environmental safety of this method allow it to be applied in practice.

Adsorption treatment using bentonite is an effective method for improving the quality of used oils. This method removes mechanical impurities, oxidation products and harmful additives from the oil, increasing its reusability. The cost-effectiveness and high adsorption capacity of bentonite make it suitable for widespread use in practice.

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DEVELOPMENT OF COMPLEX TECHNICAL SYSTEMS. (Development of Complex Technical Systems Using Computer-Aided Engineering Programs with Artificial Intelligence and Artificial Neural Network Elements)

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Abstract

This paper examines the methodological foundations for the formation of complex systems of specialized technological equipment in accordance with contemporary requirements of digital design. Particular attention is given to preserving the applicability of TRIZ and ARIZ tools in the context of integrating machine-based design systems with elements of artificial intelligence.

The structure of dual parallel local subsystems is analyzed. These subsystems consist of multiple local technical systems interconnected through programmable processors and integrated into a central processor of a higher-level complex technical system. It is demonstrated that the architecture and interaction of local technical solutions are fundamentally governed by the laws of technical system evolution as formulated within TRIZ.

For a more in-depth analytical perspective, the paper proposes referring to examples of modern developments, taking into account interpretative comments on the laws of technical system evolution, as well as modifications of TRIZ and ARIZ definitions and classifications presented in the publications of the successful innovation specialist Mykyta Liakh.

Keywords: *Technical system; Complex technical system; Computer-aided engineering (CAE) program; Artificial intelligence; Artificial neural networks; TRIZ and ARIZ definitions; TRIZ and ARIZ classifications*

Structure and Interaction of Local Technical Subsystems within a Complex Technical System

Accordingly, each such dual parallel local subsystem consists of multiple local technical systems (subsystems) interconnected through local programmable processors and integrated into the central processor of the higher-level complex technical system.

The structural configuration and interaction of local technical solutions within each subsystem are fundamentally determined by the laws of technical system evolution as formulated within TRIZ.

Figure 1.

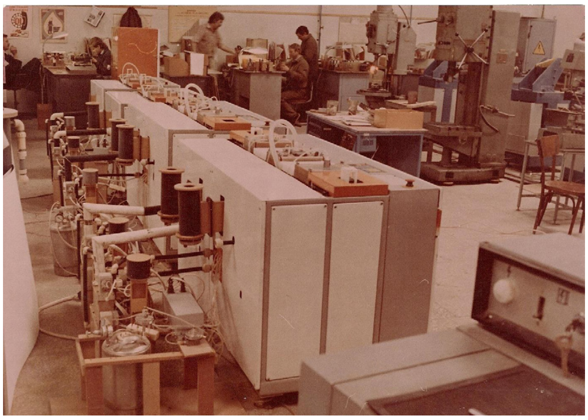


Figure 1 illustrates an automated production line for applying electroplated coatings to thin-film microassembly boards. This represents a higher-level complex technical system incorporating a series of interrelated technical systems connected through a unified technological cycle. These systems operate as dual parallel local subsystems, each comprising two coordinated processing lines chemical and mechanical integrated with electroplating operations.

For a more detailed analytical examination, it is appropriate to refer to examples of specific contemporary developments, taking into account the previously provided commentary on the laws of technical system evolution, as well as certain modifications of TRIZ and ARIZ definitions and classifications proposed in the well-known publications of the successful innovation specialist Mykyta Liakh.

Figure 2.

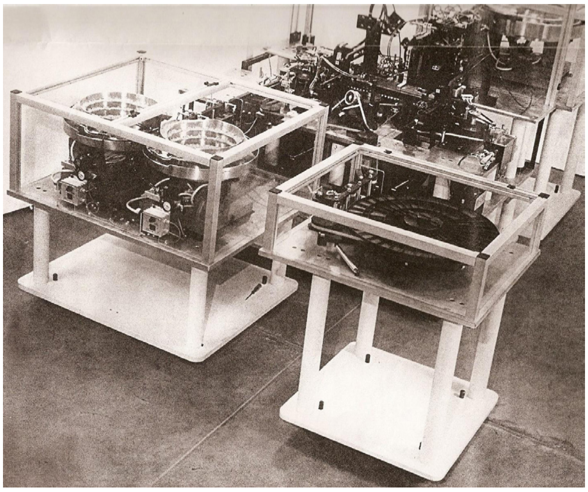


Figure 2 presents the technological modules of an automated robotic production assembly complex designed for the autonomous manufacture of contact blocks for telephone lines. As shown in the figure, the complex comprises four primary technological modules, three of which serve as part-preparation modules and are arranged around the central assembly module – the conveyor system.

The operating cycle of each module is synchronized with the pitch (operating cycle) of the assembly conveyor module. This applies both to traditional modules used in such systems – for example, vibratory feeder (hopper) modules (shown on the left in the figure) – and to fundamentally new modules for contact stamping and subsequent transfer to the assembly and inspection conveyor (shown in the center).

Such an automated robotic production assembly configuration may be classified as a technical system with a rigid production cycle, wherein all technological modules of the complex are directly tied to the operational step of the assembly conveyor module.

Within this configuration, the technological modules perform the functions of subsystems, while the assembly conveyor module functions as the leading supersystem, to whose production cycle the subsystem modules are synchronized and subordinated.

As evident from the figure, despite the presence of numerous interaction points and synchronization requirements among production cycles, the system does not incorporate regulatory mechanisms aimed at increasing flexibility or enabling dynamic adjustment of module operating cycles.

This configuration is characteristic of complex technological solutions with a fixed operating cycle that is neither intended nor designed to be modified during the execution of the production process.

Logically, such complexes do not initially require computerization and can successfully operate within an automated production cycle designed for the mass manufacture of standardized products.

For a technical system performing tasks of this nature, all definitions of the classical technical system remain unchanged.

Likewise, the definitions and classification methods of its components – supersystems and subsystems – remain applicable without modification.

With regard to the specific structure and features of the automated robotic production complex, it is important to note elements of fundamental novelty within the overall technological configuration of the system and the characteristics of the product manufactured.

This primarily concerns the specific design of the contacts within the contact blocks.

As illustrated in the figure, a strip of special bronze with a high beryllium content is not fully stamped in the initial stamping module. Instead, it is only partially formed with contour incisions. The strip is then transferred to another module (located on the opposite side of the assembly conveyor module), where it is finally shaped into paired contacts and inserted into the appropriate conveyor cells, which already contain the plastic components of the contact block.

For complexes of this type, this represents a fundamentally new solution. It allows the system to maintain a constant production rhythm for contact blocks and eliminates the need for intermediate real-time inspection.

For the classification of a modern automated robotic production assembly complex designed for the autonomous manufacture of contact blocks for telephone lines, updated definitions of technical systems and their constituent elements may be applied, as developed and proposed by the well-known researcher and innovation specialist Mykyta Liakh in his works.

Figure 3.

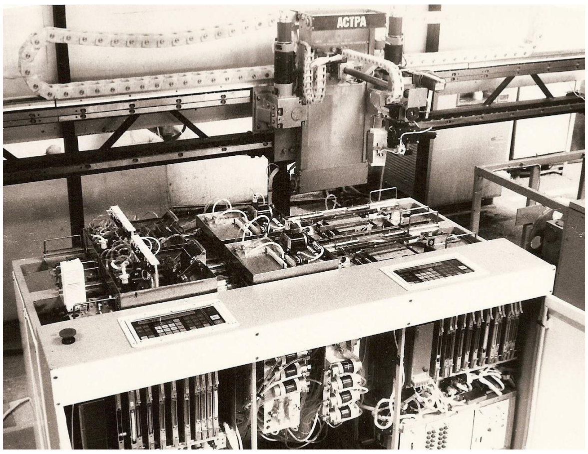


Figure 3 presents a configuration of a flexible photolithography processing module for thin-film microassembly boards.

The module incorporates two parallel technological processing streams. It is important to emphasize the complete operational autonomy of each stream, including the independence of their respective comprehensive computer control systems. In addition to these control systems, the module also includes a computer-based control and monitoring system for the operator robot, functionally integrated with the comprehensive control systems of both processing streams.

The specified module comprises several closely interconnected functional technical systems, each of which may be classified as a supersystem.

The aggregate of these systems includes loading and unloading modules, local loading – unloading units, transport tracks, centrifuges (spin-coating units), dosing and delivery units for chemical reagents and photoresist to the processing zone and centrifuge platform, as well as monitoring and control systems, among others.

Figure 4.

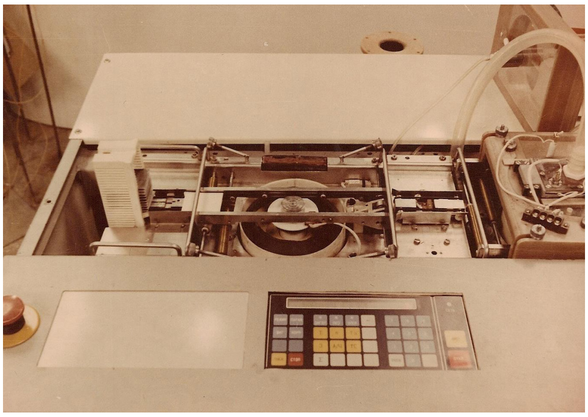


Figure 4 illustrates the working track of an electroplating installation designed for applying galvanic coatings to thin-film microassembly boards.

The working track includes an autonomous loading and unloading unit installed at both the process entry and exit points.

The track comprises several centrifuge units corresponding to distinct process stages:

- a working position for surface preparation prior to coating;
- a working position for electroplating deposition;
- a working position for final post-coating treatment of the board.

The system is fully automated and controlled by programmable processors interfaced with the power supply unit for the electroplating process, allowing flexible regulation of current density depending on coating area and required thickness. The system incorporates two operational streams, one of which is shown in the figure. Control, adjustment, configuration, and monitoring of the system are performed through multiple programmable controllers, with programs, parameters, and commands entered via a touchscreen interface. It is important to note that each local technical system – even at the level of a lower-order subsystem – due to a high degree of unification and standardization, possesses significant potential for integrative adaptation within technical systems across the entire hierarchy that defines the composition and functional characteristics of the leading supersystem.

Given that, in practical industrial settings, prototypes of such equipment are typically developed at the level of invention, the correct definition, systematic qualification, and classification of all new technical solutions and their combinations across technical systems at all hierarchical levels are of critical importance.

Figure 5.

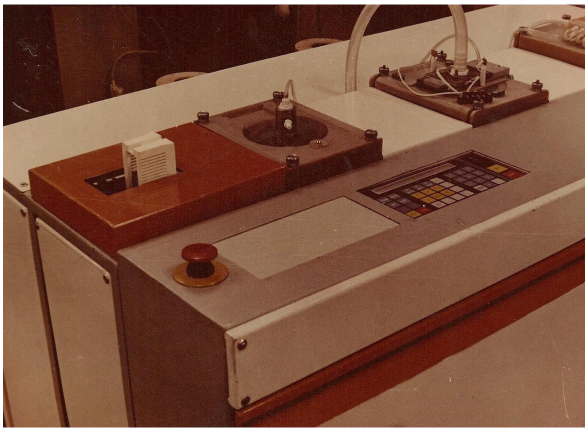


Figure 5 illustrates an automated electroplating installation designed for the application of galvanic coatings to thin-film microassembly boards under semiconductor manufacturing conditions.

The installation consists of two technological processing streams and provides a flexible and independently controlled configuration for monitoring and operational management. It is designed for integration into continuous flexible technological modules, which in turn may be incorporated into higher-level technical systems.

As shown in the figure, thin-film microassembly board blanks manufactured from specialized ceramic material (dimensions 48 × 60 mm) are placed in cassettes installed at both the beginning and end of the technological flow.

Operator participation in the process is not required, as all loading and unloading operations are performed by a robotic handling unit. Control of all operations and sequencing of control commands are carried out by a programmable processor, with user interaction provided via a touchscreen control interface.

Figure 6.

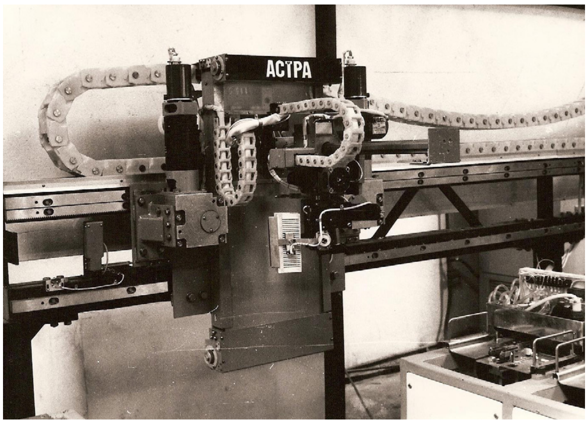


Figure 6 shows a flexible automated technological module from the perspective of the input devices, onto which the loading – unloading robot places a cassette containing blanks for thin-film microassembly boards.

The robotic manipulator retrieves the cassette from a storage cell, transfers it to a position aligned with the input device table, then lowers the cassette until it contacts the table surface and secures it in position.

The illustrated configuration of local technical systems may be classified as a combination of subsystems integrated into a localized yet functionally higher-level supersystem through a specific flexible algorithm governing the entire complex sequential process. This process includes: locating the cassette; identification and gripping of the cassette; transportation of the cassette; three-dimensional orientation; vertical alignment; identification of the cassette on the loading–unloading input table; and final fixation of the cassette on the table with subsequent transfer of operational functions to the conveyor track.

All of the aforementioned operations simultaneously constitute the technical specification for the development of the corresponding control software.

Figure 7.

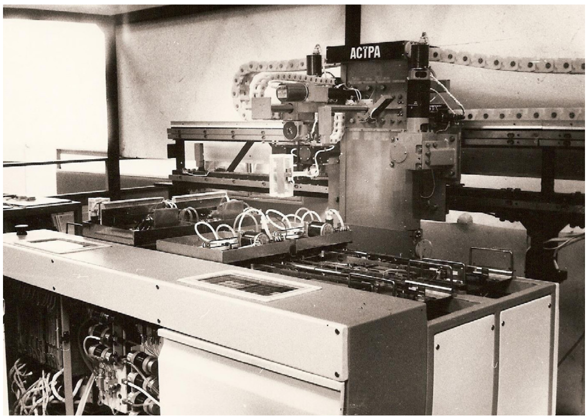


Figure 7 illustrates the technical solutions that constitute and define the transport systems at all hierarchical levels of the flexible automated technological module. These systems range from the transportation of thin-film microassembly board blanks from the loading–unloading module to the various working positions, to the comprehensive transport system of the robotic manipulator, which is capable of adaptation for integration with equipment of other technological domains and with computerized control and dispatch regulation systems.

As a rule, systems of this type incorporate a wide range of foundational technical solutions. The combination of these base solutions with technical solutions possessing worldwide novelty makes it possible to classify comprehensive configurations of such integrated technical solutions – in various combinations and structural arrangements – as inventions.

Figure 8.

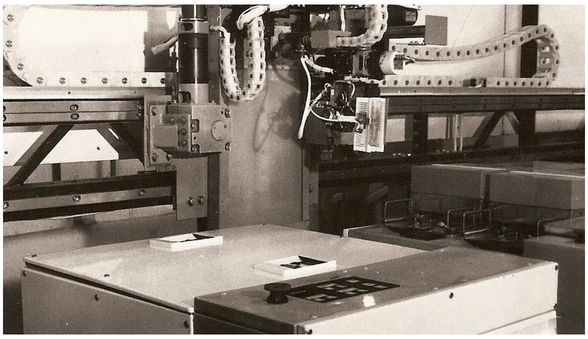


Figure 8 illustrates the integration of the transport systems of a flexible automated technological module with the transport–orientation systems of the accumulator module, functioning as a universal supersystem.

In such a configuration – characterized by ascending and descending technical solutions within the hierarchical structure of the highest-level supersystem – the strategy of patent (technical) and licensing (legal) protection is highly dependent on the precise and technically correct qualification of the entire complex of technical solutions, their functional interconnections, and, more importantly, their correlation with the definitions and classifications of various types of technical solutions.

This includes their relationship to subsystems at higher hierarchical levels and to the technical solutions that connect local and relatively autonomous technical systems into supersystems. Accurate systemic classification at these interface levels is essential for both technical integrity and legal defensibility.

Naturally, the presence of programmable control and monitoring processors elevates the status of such systems from a local technical system to a smart technical system.

All of the above demonstrates the importance of the analytical work conducted in the pioneering research of Mykyta Liakh. His developments addressing fundamental issues of classification and systematization of technical system types and characteristics, as well as the formulation of definitions for each hierarchical level of technical *systems, are essential for the systematic advancement and further optimization of machine-based design processes. This is particularly relevant in the context of applying modern computer-aided engineering tools in combination with advanced digital technologies and their integration with the terminology and laws of technical system evolution established in TRIZ and ARIZ.*

Figure 9.

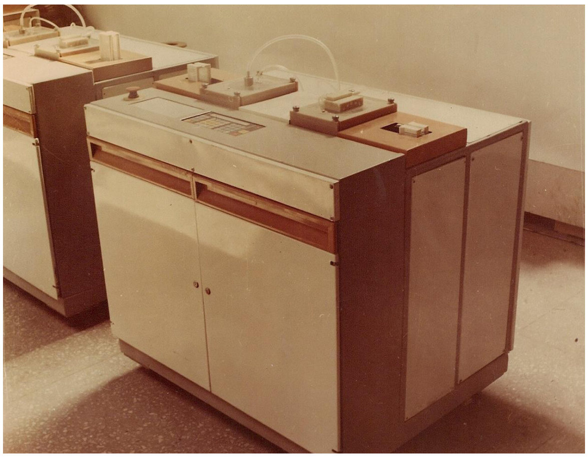


Figure 9 illustrates a continuous automated production line for the complete cycle of photolithography and techno-chemical processing of thin-film microassembly boards, featuring a flexible organization of local technological processes within each installation included in the line.

According to TRIZ classification, the production line constitutes a highest-level technical system within the hierarchy – a supersystem. Each installation within the line represents a mid-level technical system – also a supersystem relative to its internal structure. Each working station within an installation constitutes a lowest-level technical system – a subsystem.

In hierarchical terms, as the system level increases, each successive system becomes a supersystem relative to the preceding one, while each preceding system is considered a subsystem within the ascending structure.

Such a structured classification substantially unifies the logical and technological interrelationships among technical systems at all hierarchical levels. It also enables a high degree of standardization of software and system-level interconnections between processors and programmable controllers across all constituent components of the automated installations and the modular technical systems of auxiliary elements incorporated into the line.

When transitioning from a systemic continuous automated production line to a systemic flexible automated technological module, all classification definitions and formulations retain their validity and conceptual consistency.

Figure 10.

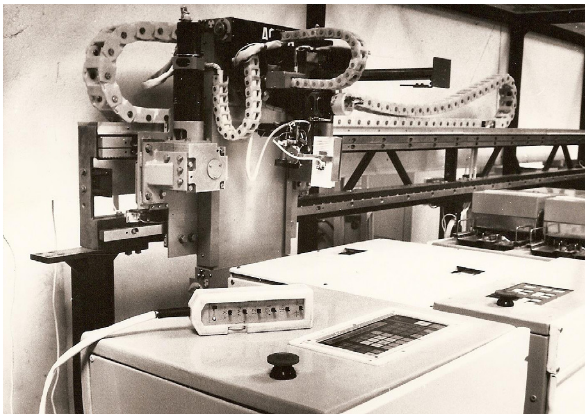


Figure 10 presents a fragment of a flexible photolithography technological module for thin-film microassembly boards, illustrating the fundamental solution for loading and unloading working stations using a robotic operator.

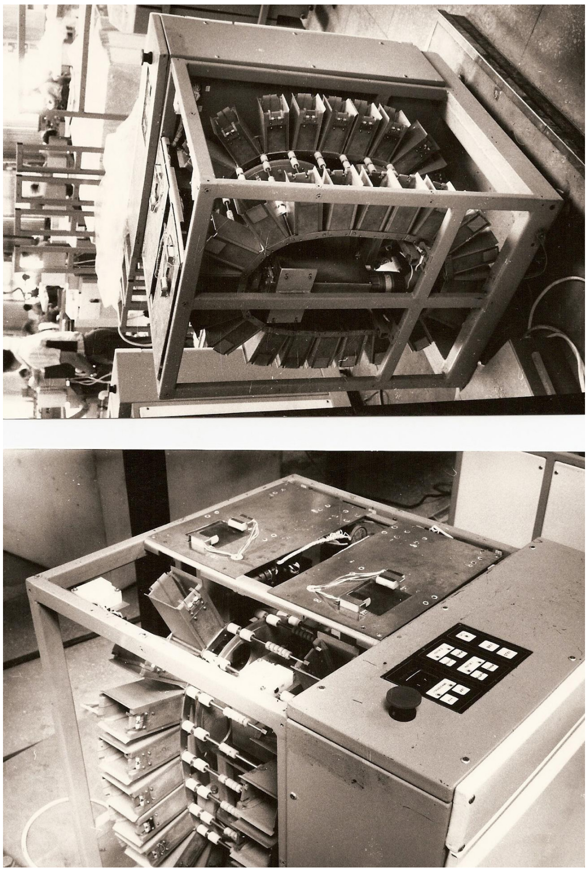
The robot retrieves a cassette containing substrates from the accumulator module and installs it onto the loading device table of the technological flow. The reverse process is performed in a similar manner – the robot grips a cassette containing processed substrates and places it into the accumulator module.

As shown in the figure, the accumulator modules are equipped with sealed cassette cells and incorporate programmable control processors that monitor the processing sequence and generate control signals for the accumulator module conveyor, indicating which cell is to be filled or cleared of a cassette.

Figure 11 illustrates the internal structure of the accumulator module. As shown in the figure, the accumulator module is equipped with a vertical conveyor system in which cells are mounted for the insertion and remov-

al of cassettes containing substrate blanks.

Figure 11.



This technical system has undergone extensive testing. A detailed analysis demonstrates that the layout, schematic design, and structural technical solutions of the constituent elements of the flexible automated production technological module – in terms of their configuration, functions, methods of arrangement, and operational principles – substantially correspond to the classification framework, terminology, and structural definitions of modified technical systems as formulated in the works and publications of Mykyta Liakh.

However, the analysis would remain incomplete without examining the standard process of developing a new technical solution as part of a higher-level technical system with a more complex compositional and structural organization. It is also necessary to assess the consistency of conventional formulations and definitions with the modified definitions and classifications of technical systems at all hierarchical levels proposed by Mykyta Liakh.

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DEVELOPMENT OF TECHNOLOGY AND INVESTIGATION OF THE PROPERTIES OF CORROSION INHIBITORS BASED ON GOSSYPOL RESIN

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Abstract

The study examines the condensation process of gossypol resin with urea within a temperature range of 50–70 °C. By adding the distillation residue of monoethanolamine to the resulting condensation product in a 1:1 ratio, a composition containing azomethine groups and π-bonds was prepared. These components facilitate adsorption on the metal surface and form stable complexes with various salts. The resulting product was used as a corrosion inhibitor, the protective efficiency of which meets the requirements for hydrogen sulfide and acidic environments. A single-stage technology for the production of the corrosion inhibitor has been proposed.

Keywords**:** *inhibitor, corrosion, mineral salts, gossypol resin, urea, protective effect, hydrogen sulfide environment*

Introduction

In nature, there are so-called abnormal phenomena – erosion, corrosion, mineral salt deposits, etc. – which cause enormous damage to the national economy. Mineral salts, carbonates, calcium, iron and barium sulphates, etc., dissolved in water, form a hard-to-dissolve scale when heated, which leads to a decrease in thermal conductivity and overconsumption of energy resources, requiring additional costs associated with the prevention of salt deposits.

Currently, well-deserved attention is being paid to the introduction of inhibitors to protect equipment from corrosion and salt deposits. The use of such inhibitors can increase the service life of expensive equipment several times over. At the same time, year after year, it has been proven that the most effective inhibitors for neutral and slightly alkaline environments are nitrogen-, sulphur- and oxygen-containing organic compounds, as well as metal-complex organophosphorus compounds – zinc organophosphonic acids, which effectively prevent corrosion and mineral salt deposits on the surface of equipment.

There are many publications devoted to the catalytic condensation of aliphatic aldehydes with ammonia in the vapour phase (Kwong, 2007), which leads to the formation of pyridines.

The production of substituted pyridines by thermal cyclocondensation of aldehydes with ammonia is called the Bayer-Chichibabin reaction (Zaitseva, 2001) and is important in the synthesis of various alkylpyridines with predetermined structures, which can be effective corrosion inhibitors (Yu, 2005). However, due to the low selectivity of the product, this method of obtaining alkylpyridines has not found practical application.

The condensation of aromatic aldehydes with aromatic amines leads to the formation of Schiff bases, which was studied in the work of (Letunov and Kulakova., 2012) using the example of the reaction of benzylideneaniline with antipyrine.

$$Ar-CHO + H_2N-Ar' \longrightarrow Ar-CH=N-Ar' + H_2O$$

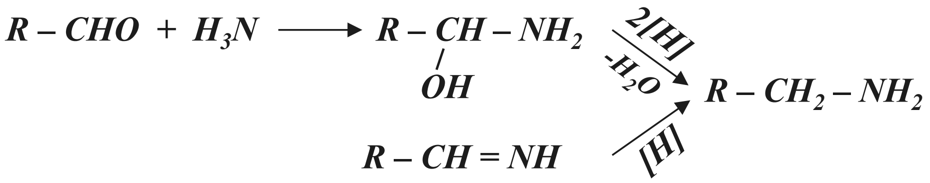
Schiff bases, obtained by the interaction of various aliphatic and aromatic aldehydes and amines, are significantly more active and inhibit metal corrosion than the starting substances. When a mixture of amines and aldehydes is used as corrosion inhibitors, Schiff bases are formed on the surface of catalytically active transition metals, which explains the synergism noted above (Rahimkulov et al., 2005).

The production of primary, secondary and tertiary amines by reduction-alkylation of carbonyl compounds is of great importance.

The reduction-alkylation reaction of ammonia consists in the addition of ammonia to a carbonyl compound and the subsequent reduction of either the addition product itself or the dehydration product of the latter.

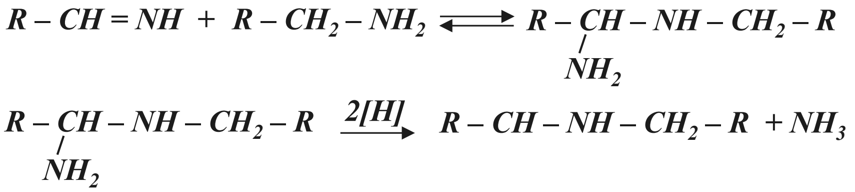
Materials and methods

In the case of catalytic reduction, the reaction is carried out in an alcoholic solution. The reaction proceeds according to the following scheme:



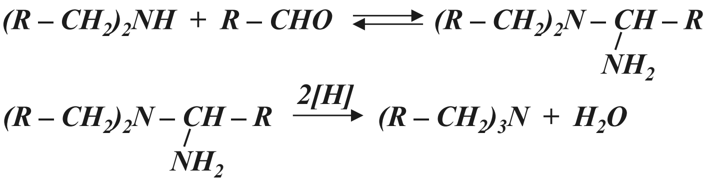
$$R-CHO + H_3N \longrightarrow \underset{\displaystyle OH}{R-CH}-NH_2 \xrightarrow[-H_2O]{2[H]} R-CH_2-NH_2$$
$$R-CH=NH \xrightarrow{[H]} R-CH_2-NH_2$$

The primary amine formed in the presence of aldehyde is also capable of reacting similarly to ammonia: the resulting addition product, Schiff base R – CH = N – CH2 – R, is converted into a secondary amine upon reduction. Similarly, a primary amine can react with an imine to form an addition product, the reduction of which also leads to the formation of a secondary amine:



$$R-CH=NH + R-CH_2-NH_2 \rightleftarrows R-\underset{\displaystyle NH_2}{CH}-NH-CH_2-R$$
$$R-\underset{\displaystyle NH_2}{CH}-NH-CH_2-R \xrightarrow{2[H]} R-CH-NH-CH_2-R + NH_3$$

In turn, secondary amines can react with either aldehydes or imines; the resulting products are reduced to tertiary amines:



$$(R-CH_2)_2NH + R-CHO \rightleftarrows (R-CH_2)_2N-\underset{\displaystyle NH_2}{CH}-R$$
$$(R-CH_2)_2N-\underset{\displaystyle NH_2}{CH}-R \xrightarrow{2[H]} (R-CH_2)_3N + H_2O$$

The reductive amination reaction of carbonyl compounds is a key reaction for obtaining amines of various structures, but the main disadvantage of this method is the formation of a mixture of products of complex composition and low yield of target products.

Among the products of the processing of aldehydes, amines and amides for the production of corrosion and scale inhibitors, the following are used:

1) imidazolines obtained as a result of chemical reactions in a vacuum reactor (the ratio of imidazoline to amide parts is 30:70);

2) amines of various structures;

3) fatty acids with 17 to 25 carbon atoms (at $C < 17$, foaming and emulsification may occur; at $C > 25$, the inhibitor will be insoluble in both water and hydrocarbons);

4) pyridines and their derivatives;

5) various oxygen-containing compounds;

6) compounds with double and triple bonds in the molecule;

7) Schiff bases;

8) additives that reduce surface tension at the water-liquid hydrocarbon interface in order to facilitate the transition of the inhibitor into water.

Diethylenetriamine is used as an amine in the production of imidazoline. If diethylenetriamine contains a large radical – R – in its composition, the inhibitor will lose its homogeneity during storage and form a precipitate in storage containers, clog injection devices, and have low thermal stability.

The three-stage reaction for obtaining imidazoline takes place in reactors under vacuum:

The reaction for obtaining imidazoline never proceeds to completion, resulting in the formation of a mixture of amide (stage 2) and imide (stage 3) in a specific ratio. At the optimum ratio (e.g., imide: amide approximately 30:70), a stable substance with high protective properties is obtained.

The aim of this work is to develop a technology for the production of mineral salt and corrosion inhibitors based on the condensation product of gossypol resin with urea, with the addition of a distillation residue of monoethanolamine.

Experimental part

Place 50 g of gossypol resin in a round-bottom flask, heat to a temperature of 50 °C and add 15 dm^3 of a 40% aqueous solution of carbamide. The mixture is heated while stirring until a homogeneous mass is formed. Then, while continuing to stir intensively, 45 g of vacuum distillation residue of monoethanolamine is added. The resulting product was tentatively named 'SUMONO-extra-M' and is characterised by the following indicators:

The SUMONO-Extra-M corrosion inhibitor is a product of the condensation of gossypol (Kobilov et al.,, 2012) with urea, a mixture of fatty acids and the vacuum distillation residue of monoethanolamine.

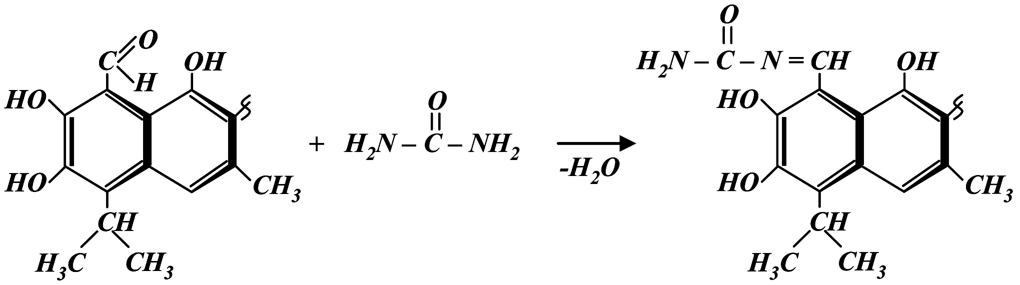
In terms of its physical, chemical and operational characteristics, the SUMONO-Extra-M corrosion inhibitor must meet the requirements and standards.

Name of indicators	Standard
Appearance	Homogeneous liquid ranging from light
Density at 20 °C, g/cm^3	1.0±0.05
Amine number, mg HCl per 1 g of inhibitor, not less than	45
Protective effect in hydrogen sulphide environment, % not less than	90.0
In hydrochloric acid with a mass fraction of... 15%, not less than	96.0
In oil, % not less than	85.0
Solidification temperature, °C, not higher than	–18
Dry residue, % not less than	67
Solubility in gas condensate in water	soluble Dispersible
Kinematic viscosity at 20 °C mm²/sec	25

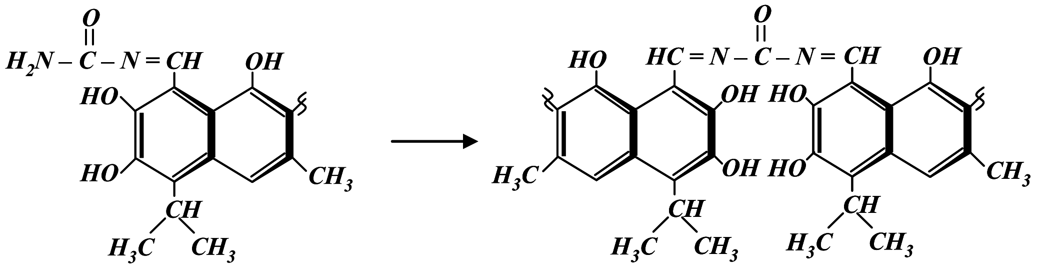
Results and discussion

The corrosion inhibitor SUMONO-Extra-M is obtained by condensing gossypol resin with a urea solution at temperatures of 40–70 °C and shifting the resulting product with the distillation residue of vacuum distillation of monoethanolamine in a ratio of 0.5:0.03:0.47.

When gossypol resin interacts with urea, the aldehyde group of gossypol forms Schiff bases according to the following scheme:



The second NH_2 group of urea can react with a new gossypol molecule and form compounds with the following structure:



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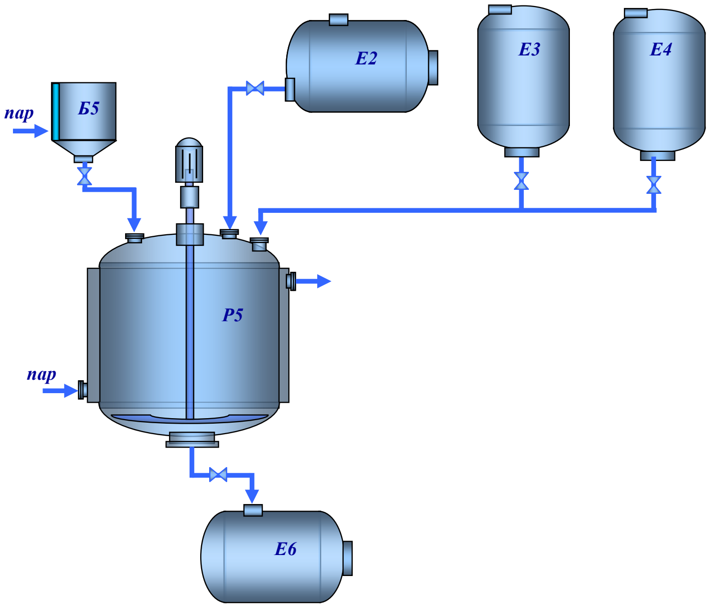
The vacuum distillation residue of monoethanolamine contains a mixture of amines and oligomers. The presence of OH groups, azomethine groups and π bonds in gossypol resin promotes the adsorption of the latter on the metal surface, forming a strong film. In this regard, the mixture of gossypol carbamide resin and the vacuum distillation residue of monoethanolamine has high protective properties.

The technological scheme for the production of the SUMONO-Extra-M corrosion inhibitor consists of a single technological line (Fig. 1):

Figure 1. *Schematic diagram of the production of the SUMONO-Extra-M inhibitor:*



B1 –hopper for gossypol resin;
E2, E3, E4 – containers for the bottom residue of vacuum distillation of monoethanolamine;
40% solution of urea and solvent (petroleum products such as petrol, kerosene, diesel fuel, etc.);
P5 – reactor;
E6 – container for finished products

Gossypol resin is fed from bunker B1 into reactor P5, which is equipped with a mechanical stirrer and a heating jacket. The gossypol resin in bunker B1 is heated to a temperature of 50–60 °C. A 40% aqueous solution of urea is fed into the reactor from the container pos. E2. The mixture is heated while stirring at a temperature of 50 °C until a homogeneous stable mass is formed. Next, an operational amount of the vacuum distillation residue of monoethanolamine is added to the reactor from container E3 and stirred for 1 hour until a homogeneous mass is formed. If phase separation is observed when the sample taken from the reactor is left to stand, stirring is continued. If the mixture is difficult to flow, a solvent (naphtha, petrol, gas condensate, kerosene, diesel fuel, etc.) is added to the mixture. The finished product is stored in container E6.

Corrosion tests were carried out on samples of pipe steel of strength category D. The test medium was a mixture of gas condensate and water in a ratio of 1:2 by volume, saturated with hydrogen sulphide to 2.5–3.0 g/l and carbon dioxide (CO2 pressure up to 1.0 MPa). The inhibitor concentration was 0.1–0.5 g/l, and the medium was stirred (Tables 2 and 3).

Table 2. *Effect of the SUMONO-Extra-M inhibitor on steel corrosion in a hydrogen sulphide environment. Room temperature*

Inhibitor concentration, g/l	Test duration, hours	Corrosion rate, g/m²·hour	Degree of protection, %
Without inhibitor	12	1.15	–
0,1		0.051	95.56
0,2		0.036	96. 86
0,3		0.014	98.86
0,5		0.013	98.9
Without inhibitor	24	0.93	–
0,5		0.018	98.04
Without inhibitor	48	0.28	–
0,5		0.09	96.78

As can be seen from the data obtained, SUMONO-Extra-M demonstrates high protection in all cases.

Table 3. *Effect of the SUMONO-Extra-M inhibitor on steel corrosion in a carbon dioxide environment*

Inhibitor concentration, g/l	Test duration, hours	Corrosion rate, g/m²·hour	Degree of protection, %
Without inhibitor	20	3.7	–
0,2	20	0.141	96.2
Without inhibitor	40	3.8	–
0,2	40	0.170	95.5
Without inhibitor	60	3.5	–
0,2	60	0.138	96.0
Without inhibitor	80	3.4	–
0,2	80	0.138	95.94

As can be seen from the data in the table, SUMONO-Extra-M effectively protects steel from corrosion in hydrochloric acid, with a protective effect of up to 95.94%.

Conclusion

Thus, by condensing gossypol resin with carbamide at a temperature range of 50–70 °C and mixing it with the distillation residue of vacuum distillation of monoethanolamine in a ratio of 0.5:0.03:0.47, the corrosion inhibitor SUMONO-Extra-M was obtained. A single-stage technology for the production of the SUMONO-Extra-M corrosion inhibitor has been proposed. It has also been established that azomethine groups and π-bonds promote the adsorption of molecules on the metal surface, providing high protective efficiency (up to 96%) in hydrogen sulphide and acidic environments.

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TECHNOLOGY FOR OBTAINING CHEMICAL REAGENT FOR DRILLING FLUIDS BASED ON LOCAL RAW MATERIALS

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Abstract

In this article, chemical reagent formulations and technology have been developed based on local raw materials and industrial waste. This study demonstrates that it is of significant scientific and practical importance in the development of resource-saving technologies, the recycling of industrial waste, and the production of high-value chemical reagents and lubricating materials for drilling oil and gas wells.

Keywords: *chemical reagent, drilling fluid, fatty acids, lubricant, technology, pH, water, viscosity*

Introduction

In Uzbekistan, the annual demand for chemical reagents amounts to 2,500–3,000 tons. Chemical reagent drilling agents are specialized additives used to optimize drilling fluid (mud) performance, ensuring efficient borehole drilling, cuttings transport, and wellbore stability. Key types include viscosity regulators (PAC), clay inhibitors, lubricants, weighting agents, and shale inhibitors. These chemicals manage fluid loss, reduce friction, control pH, and protect drilling equipment. Chemical reagents perform several key functions in the drilling process. Drilling lubricants are specialized chemical additives added to drilling fluids (mud) to reduce torque, drag, and friction between the drill string and borehole walls. They enhance drilling efficiency, prevent sticking or jamming of pipes, and protect equipment from wear. Types include water-based (ester-based), oil-based, and glycols (Ahmet et al, 2013). The volume of oil production is around 350–400 thousand tons, and in this process an average of 30–60 kg of soapstock is generated per 1,000 kg of refined oil. Annually, 7–10 thousand tons of soapstock waste are generated nationwide. In percentages, approximately 8–12% is soapstock, 3–5% gossypol resin and 25–30% is meal waste. In recent years, a number of scientific research projects have been carried out to improve soapstock recycling technology. In this context, the recovery of valuable products – particularly surfactants – from the waste through recycling is of significant scientific and practical importance.

Surfactants are play important role for obtaining lubricants. Surfactants (surface-active agents) are organic substances that exhibit activity at the interface between liquids or between a liquid and the gas phase. They form structures between water and oil, or between a gas and a liquid, influencing the physicochemical processes in these environments. An SAA molecule consists of two parts: a hydrophilic (water-attracting) and a hydrophobic (water-repelling, oil-attracting) part. Due to the presence of these two parts, they can effectively control the processes of emulsification, wetting, dispersion and adsorption (Amiril et al., 2017).

Materials and methods

For obtaining lubricant were used following ingredients: Cotton oil and pistachio oil industry waste – soapstock, sodium hydroxide, sodium carbonate and other ingredients were selected. The industrial by-products of cottonseed and peanut oil contain high-molecular-weight fatty acids, glycerine and polyphenolic compounds, which serve as the primary raw materials for SAA (Surface active agent) synthesis.

The SAA derived from pistachio oil soapstock, being rich in oleic acid, exhibits high foam stability and cleansing ability.

Both types of surfactants are well-soluble in water, reducing the surface tension from 70 mN/m to 37–40 mN/m, which demonstrates their effective surfactant properties.

Determining the foaming ability of surfactants is an important indicator in assessing their technological and functional properties (Dina Kania et al., 2015). The following outlines the sequence of the determination method and the procedure for assessment:

1. A 0.1% solution is prepared (1 g of SAA is dissolved in 1 litre of water).
2. 50 ml of the solution is poured into the cylinder.
3. The cylinder is capped and shaken vigorously 25 times (or mixed in a special mixer) to form a foam.
4. After the foam has formed, the total volume (solution + foam) is determined by the marks on the side of the glass.
5. After the foam has formed, the volume of the foam is recorded after 1, 3, and 5 minutes.

The stability is assessed by the rate of volume reduction over time.

$$F = V_2 - V_1$$

where:

F is the foaming capacity (ml); V_2 is the total volume after foaming (ml); V_1 is the initial solution volume (ml).

Foam stability (***S***):

$$S = V_1 / V_0 \cdot 100\%$$

where:

V_1 – the volume of the foam at a given time (after 5 minutes);

V_0 – the initial volume of the foam.

Results and discussion

Cotton seed oil soapstock is a by-product of the oil and fat industry, primarily generated during the processing, i.e. refining, of oils. Its composition includes various fatty acids, neutral fats, phosphatides and other organic substances. Cotton seed oil soapstock is inexpensive yet a highly valuable raw material.

Pistachio oil soapstock is a fatty by-product of the pistachio oil production process, consisting mainly of unsaponifiables, insoluble fractions, and soluble fatty acid salts. Its composition is similar to that of soya, sunflower or cottonseed soapstocks, but it also contains substances characteristic of pistachio oil.

Due to the high content of fatty acids and soaps in pistachio oil soapstock, its processing yields surfactants, emulsifiers, or biodegradable fatty acid esters (Kobilov et al., 2023).

The main physicochemical parameters of the surfactant include the following:

1. Surface tension is a physical phenomenon associated with the force of interaction between molecules at the surface of a liquid. In other words, the surface of a liquid is different from its bulk, and some of its molecules are in contact with air or another medium. Reducing surface tension indicates the efficiency of the SAA.
2. Rheological properties – the viscosity and stratification ability of the substance are of particular importance. The flow of SAA in a liquid depends on its concentration, temperature, and molecular composition. High-viscosity SAAs keep emulsions sta-

ble, whereas low-viscosity ones disperse quickly.

3. Set time and stability are the long-term properties of the SAA in response to air and temperature, representing the time taken for the emulsion, suspension, or coating material based on it to transition from a liquid to a solid state. Drying time and stability depend on the composition, concentration, temperature and humidity of the environment. Stability is the ability of the SAA to retain its physical and chemical properties over time.
4. The stability of a phase emulsion is the ability of the substance on which it is based to keep its oil and water phases from separating for a long time. The oil droplets are dispersed in water, or the water droplets are dispersed in oil. The function of the SAA is to stabilise this dispersion and prevent the phases from separating. This layer weakens the attractive forces between the oil and water molecules, resulting in a stable emulsion. The molecules are located in hydrophilic and hydrophobic regions.
5. Chemical stability is the ability to retain its properties despite changes in pH, temperature, and ionic concentration. The functional molecules of the SAA (hydrophobic and hydrophilic groups) are sensitive to chemical influences. A stable surfactant does not lose its effectiveness under various conditions. In acidic or basic media, the surfactant's particles and molecules can alter their strength. A stable surfactant can maintain an emulsion across different pH conditions. Ions such as sodium, potassium, and calcium can cause the SAA particles to aggregate and reduce their activity. The stable SAA is not harmed by ionic effects and maintains the emulsion (Cao-Romero-Gallegos et al., 2024).

Below is a comparative presentation of the physicochemical parameters of the surfactants obtained from cottonseed oil soapstock and pistachio oil soapstock, based on scientific data and laboratory results. These data are typical of anionic surfactants derived from oil and fat waste.

Figure 1. *Technological scheme for the production of a chemicals-lubricant*

1 – Caustic soda tank;
2, 6, 7, 8, 10, 12 – Dosers;
3 – tap for water;
4 – reactor;
5 – soapstock container;
6 – sodium carbonate container;
9–10 – screw mixer;
11 – drying chamber;
13 – finished product packaging

The surfactant obtained from peanut oil soapstock produces good foam and has high stability (75–83%), whereas the surfactant from cottonseed oil soapstock shows a slightly lower value (60–74%).

A surfactant that produces stable foam is highly soluble in water and has a high molecular weight.

At low concentrations, there is almost no foam. As the concentration increases, the foam volume grows rapidly and stability improves. Surfactants are substances in liquid or dispersed form that exhibit activity at the water–oil interface. Their efficiency depends on their physical and chemical properties, as well as the production technology (Figure 1).

The technological stages for producing a surfactant based on soapstock consist of the following:

1. Preparation of the raw material.
2. The resulting polymeric fatty compounds are treated with an caustic solution, resulting in the formation of sodium salts of surfactants.
3. The product is treated with Na_2CO_3 to convert it into a powder.
4. Analysis of the finished product. Surface tension is determined (droplet counting method). Foaming capacity, emulsion stability, and biodegradability are assessed.

Surfactants obtained from the recycling of waste oil and grease are not only economically efficient but also an environmentally sustainable solution. They can be used in various fields – as cleaning agents, emulsifiers, and in textile and agricultural product processing.

Furthermore, based on the research findings, it was determined that the physicochemical properties of SAA can be controlled by varying its concentration. This makes it possible to create new composite materials, develop resource-saving technologies and increase the efficiency of waste recycling. Refining soapstock not only yields economic benefits but also reduces waste and protects the environment. The development of soapstock recycling technologies in Uzbekistan makes a significant contribution to enhancing the country's industrial potential and producing import-substituting products.

Conclusion

Recycling waste from the oil and fat industry to obtain surfactants is an ecotechnological and economically efficient method. This technology ensures that the waste is harmless to the environment and enables its recycling. A sample derived from soapstock was observed to significantly reduce surface tension, indicating its good emulsifying and wetting properties. Furthermore, the rheological and thermodynamic stability of the obtained substances was determined, ensuring their long-term activity in an aqueous medium. This method is of significant importance for the introduction of resource-saving and environmentally friendly technologies in the oil and fat industry.

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PARADOXICAL PHENOMENA AND PROPERTIES DISCOVERED IN FUEL EMULSIONS. (Paradoxical Phenomena and Properties Discovered in Fuel Emulsions Obtained in Closed Dynamic Flows of Liquid Components)

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Abstract:

In this publication, the author returns to the issue of three-dimensional hydraulic shape memory in emulsions obtained using a comprehensive method invented by him and implemented in a multifunctional apparatus also developed by him for this purpose.

Keywords: *Paradoxical phenomena and properties; Fuel emulsion; Closed dynamic flow of liquid emulsion components; Hydraulic shape memory; Hydraulic shape memory in emulsions; Three-dimensional hydraulic shape memory in emulsions; Multifunctional apparatus; Test bench formation; Trends in emulsion applications; Diesel engine; Boiler; Turbine; Injection process; Injection and combustion process; Hardness salt concentration; Fuel flow separation upstream of the high-pressure pump; Fuel injection into the combustion chamber; Fuel tank; Static mixer; Integrated testing; Modern production diesel engine; Paradoxical properties of emulsions; Working diameter of the device; Emulsion destruction also exhibits paradoxical features; Secondary emulsion*

The testing of the technology and the apparatus was carried out on water-in-oil type emulsions, in which diesel fuel No. 2 was used as the oil phase and ordinary drinking water as the aqueous phase, with a hardness salt concentration of up to 200 milligrams per liter.

In the formation of the test bench, the latest trends in the application of emulsions as fuel were taken into account, both for modern diesel engines and for diesel generators, industrial boilers, and turbines.

For diesel engines and boilers, the most challenging stage in the injection and combustion process is the separation of the fuel flow upstream of the high-pressure pump, when the majority of the fuel flow is directed to the high-pressure pump (today operating at pressures of 2,000 bar and higher), after which it is injected into the combustion chamber of the boiler or into the engine cylinders, while a smaller portion is returned to the fuel tank.

In the case of using single-component diesel fuel, this principle does not create any problems. However, when emulsions are employed, such a fuel supply method leads to disturbances in emulsion stability, as well as нарушению its homogeneity and uniformity in the volumetric distribution of water and oil (diesel fuel).

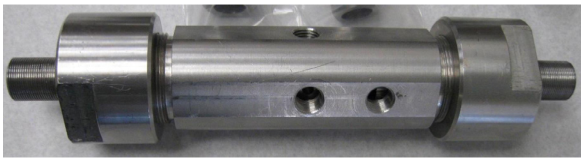
The emulsion preparation method based on the formation of microcapsules made it possible to achieve complete re-formation of the emulsion with minimal time expenditure (in less than one second).

The device itself for producing this type of emulsion of various kinds represents an exceptionally simple and compact cylindrical structure with no moving parts – a so-called static mixer – in which the emulsion formation process lasts no more than a fraction of a second.

This device is highly versatile and can operate at pipeline pressures ranging from 3 bar to 50 bar (in a modern diesel engine, the fuel line pressure is approximately 3 bar).

For comprehensive testing, a system was developed that included the device itself and a tank for emulsion re-formation, along with all associated peripheral components and pumps required for emulsion re-formation.

Figure 1.



This system was configured as follows:

Figure 2.

This system is integrative in nature, since both the primary production of the emulsion and the re-formation of the emulsion are carried out on the same unit, while identical technological methods are employed.

The working diameter of the device is only 25 millimeters, and at a line pressure of 3 bar it provides a throughput of 50 liters per hour for the primary formation of the emulsion and 25 liters per hour for the re-formation of the emulsion.

The next photograph shows a 10-gallon emulsion tank installed in the fuel system of a modern production diesel engine with a displacement of 2.4 liters.

Figure 3.

In this tank, the emulsion re-formation process takes place, which is based on a paradoxical property of the emulsion obtained using the invented apparatus – namely, that the emulsion exhibits three-dimensional hydraulic shape memory.

What is the meaning of this interpretation of the distinctive feature of the invented emulsion?

Based on the results of more than 1,000 tests conducted on a diesel engine using the specified emulsion, it has been determined and demonstrated that:

- the emulsion, after a certain period following its formation, undergoes destruction and separates into two layers – one consisting of diesel fuel with a water admixture and the other consisting of water with a diesel fuel admixture;
- in both cases, the content of admixtures does not exceed 5%;
- under short-term (within 15–25 seconds) hydrodynamic activation of the destructured emulsion, it fully returns

to its original state – a liquid medium composed of three-dimensional capsules containing micro- and nanoscale water droplets surrounded by shells of diesel fuel.

Figure 4.

The photograph shows the emulsion immediately after formation. This emulsion contains 20% water (with the water being ordinary drinking water without additional purification, having a mineral salt content of approximately 200 milligrams per liter).

Approximately one hour after preparation, the emulsion undergoes destruction and acquires the appearance shown in the following photographs.

Figure 5.

Two layers are visible, and these layers are transparent, which indicates that the particle sizes in this liquid do not exceed 200 nanometers (otherwise, if the particle sizes were larger, the liquid would not be transparent).

The liquid (emulsion) was sampled two days after the initial preparation of the emulsion.

Figure 6.

This photograph shows the liquid prior to the start of the emulsion re-formation process.

It should be noted that the destruction of the emulsion also exhibits paradoxical features, since in both the layer with a predominance of water and the layer with a predominance of diesel fuel, emulsion capsules with a characteristic multilevel structure are visible under a microscope. In this structure, the core of the spherical capsule is a microdroplet of water surrounded by a shell of diesel fuel.

During hydrodynamic activation in the re-emulsification process, new capsules begin to form around the preserved capsules, and the formation process is exceptionally short-term and highly efficient, with minimal energy expenditure.

In addition, the emulsion re-formation process also increases the stability and robustness of the re-formed emulsion in the final product, which is extremely important for many industries in which so-called secondary emulsions are used – for example, the application of this method for preparing emulsions for hydroponic systems in greenhouse farming, where preserving the emulsion structure for as long a period as possible is critical.

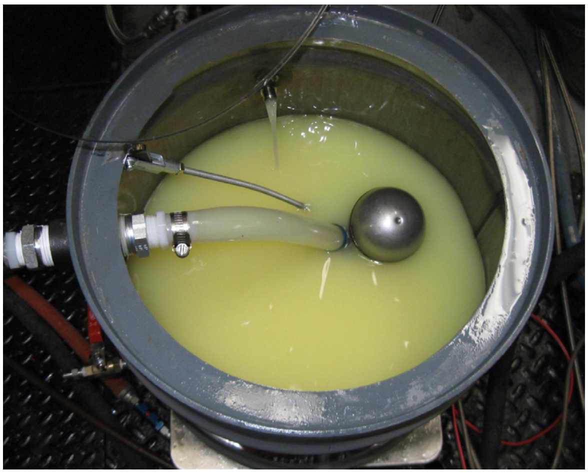
This photograph was taken at the moment the emulsion re-formation process begins. As can be seen, the liquid in the intake pipe is transparent, although it has a greenish tint due to the diesel fuel.

Figure 7.

The liquid is supplied to a conventional centrifugal pump and then returned back to the tank. As can be seen, the liquid returns already white in color, with the upper inlet serving as a signaling inlet, while the main return inlet is located in the lower part of the tank.

Thus, when considering this process as applied to hydroponic systems in modern greenhouses, one can observe a substantial potential inherent in these technological methods for the continuous and virtually infinite regeneration of hydroponic liquids and solutions, with the additional potential capability of electrochemically modifying the acidity (pH) of the water in the emulsion.

Figure 8.

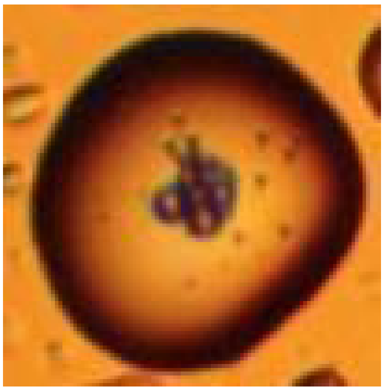


This photograph shows the emulsion after several seconds of treatment; externally, it fully corresponds to the original appearance of the emulsion.

The engine performance results obtained with the newly produced emulsion and with the re-formed emulsion are completely identical.

The same results were obtained on industrial boilers and diesel generators.

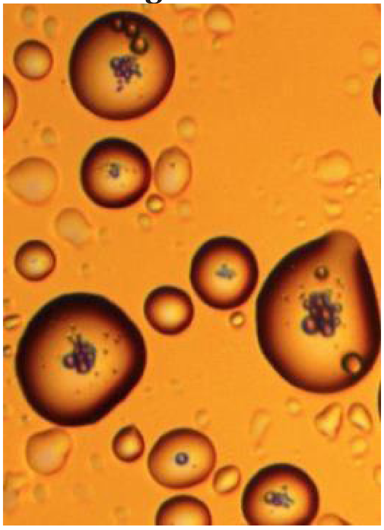
Figure 9.



The photograph shows the emulsion capsules under a microscope, with their three-dimensional structure clearly visible.

Several spherical cores are visible within the core of the capsule – these are also capsules. They differ in significantly smaller dimensions than the primary capsule (that is, if the size of the large capsule ranges from one to three micrometers, then the sizes of the internal capsules are each no more than 300 nanometers, and measurements have recorded capsules with sizes not exceeding 120 nanometers).

Figure 10.



During the phase separation of the emulsion, it is precisely the smallest capsules that remain within the layers – those with sizes of 100–200 nanometers (this is evident from the chemical analysis of the separated layers, which showed a 5% admixture of diesel fuel in water and a 5% admixture of water in diesel fuel).

Thus, it is due to these admixtures that the emulsion re-formation process takes place, in which nanoscale capsules once again become the centers of microcapsules.

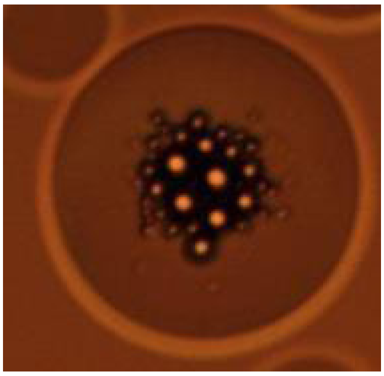
This process exhibits a distinctly three-dimensional character and, since it occurs in a liquid medium, it has been designated as hydraulic.

Since after separation the emulsion acquires a completely different appearance, and since after re-formation it fully returns to its original appearance, we have every reason to consider that the emulsion possesses three-dimensional hydraulic shape memory (of the emulsion capsules).

This phenomenon was fully confirmed when operating with emulsion volumes of 1,000 liters and activating them by simple stirring.

All of this was carried out on an industrial boiler with a capacity of 10 tons of steam per hour, at emulsion proportions of 20%, 40%, and 50% water. At all proportions, the results of the emulsion's restoration to its original appearance were fully confirmed, including after three months following the initial preparation of the emulsion.

Figure 11.



Since the emulsion was also produced on the basis of heavy diesel fuel, the micrograph shows the structure of a microcapsule of such an emulsion.

The next photograph shows an emulsion obtained with a water content of 25% in diesel fuel № 2.

Figure 12.

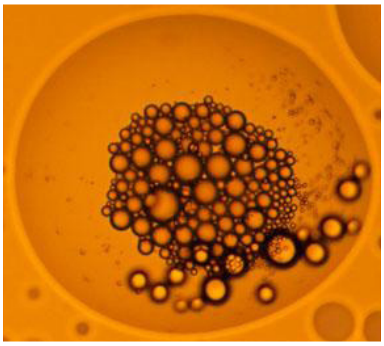


Figure 13.

Figure 14.

This photograph shows a tank containing 1,000 liters of emulsion equipped with a hydromechanical activator. This tank was installed on an industrial boiler with a capacity of 10 tons of steam per hour.

The emulsion was produced in advance (the period from emulsion production to combustion reached up to two months or more).

The use of a simple hydromechanical activator makes it possible to initiate the emulsion re-formation process with minimal electrical energy consumption (electricity consumption is within 7 cents per hour at a fuel emulsion consumption rate of 1,200 liters per hour).

To assess the feasibility of applying emulsion formation and emulsion re-formation technologies in irrigation systems of modern greenhouses, the results demonstrated in relatively large liquid volumes have shown a high potential for effectiveness.

The constant presence of intensive hydrodynamic воздействия on a hydroponic liquid solution with a formed emulsion makes it possible, in addition to merely preserving the properties and parameters of the emulsion, also to optimize certain parameters and characteristics of the formed emulsion in the solution for the further intensification of the agricultural production process itself.

It must be acknowledged that the primary informational material presented in this publication, concerning paradoxes in the innovative formation of emulsions in the process, requires, in addition to fuel technologies, detailed adaptation and integration into all possible related technological processes.

List of References, Patent and Licensing Information:

United States Patent Application	**20100243953**
Kind Code	**A1**
	September 30, 2010

Method of Dynamic Mixing of Fluids

Abstract

Methods are provided for achieving dynamic mixing of two or more fluid streams using a mixing device. The methods include providing at least two integrated concentric contours that are configured to simultaneously direct fluid flow and transform the kinetic energy level of the first and second fluid streams, and directing fluid flow through the at least two integrated concentric contours such that, in two adjacent contours, the first and second fluid streams are input in opposite directions. As a result, the physical effects acting on each stream of each contour are combined, increasing the kinetic energy of the mix and transforming the mix from a first kinetic energy level to a second kinetic energy level, where the second kinetic energy level is greater than the first kinetic energy level.

United States Patent Application **20100281766**
Kind Code **A1**
November 11, 2010

Dynamic Mixing of Fluids

Abstract

Methods, systems, and devices for preparation and activation of liquids and gaseous fuels are disclosed. Method of vortex cooling of compressed gas stream and water removing from air are disclosed.

United States Patent Application **20110030827**
Kind Code **A1**
February 10, 2011

FLUID COMPOSITE, DEVICE FOR PRODUCING THEREOF AND SYSTEM OF USE

Abstract

The current disclosure relates to a new fluid composite, a device for producing the fluid composite, and a method of production therewith, and more specifically a fluid composite made of a fuel and its oxidant for burning as part of different systems such as fuel burners, where the fluid composite after a stage of intense molecular between a controlled flow of a liquid such as fuel and a faster flow of compressed highly directional gas such as air results in the creation of a three dimensional matrix of small hallow spheres each made of a layer of fuel around a volume of pressurized gas. In an alternate embodiment, external conditions such as inline pressure warps the spherical cells into a network of oblong shape cells where pressurized air is used as part of the combustion process. In yet another embodiment, additional gas such as air is added via a second inlet to increase the proportion of oxidant to carburant as part of the mixture.

United States Patent Application **20110048353**
Kind Code **A1**
March 3, 2011

Engine with Integrated Mixing Technology

Abstract

The present disclosure generally relates to an engine with an integrated mixing of fluids device and associated technology for improvement of the efficiency of the engine, and more specifically to an engine equipped with a fuel mixing device for improvement of the overall properties by inline oxygenation of the liquid, a change in property of the liquid such as cooling form improved combustion, or the use of re-circulation of exhaust from the engine to further improve engine efficiency and reduce unwanted emissions.

United States Patent Application **20120085428**
Kind Code **A1**
April 12, 2012

EMULSION, APPARATUS, SYSTEM AND METHOD FOR DYNAMIC PREPARATION

Abstract

The invention relates to a fluid composite, a device for producing the fluid composite, and a system for producing an aerated fluid composite therewith, and more specifically a fluid composite made of a fuel and its oxidant for burning as part of different systems such as fuel burners or combustion chambers and the like. The invention also relates to an emulsion, an apparatus for producing an emulsion, a system for producing an emulsion with the apparatus for producing the emulsion, a method for producing a dynamic preparation with the emulsion, and more specifically to a new type of a stable liquid/liquid emulsion in the field of colloidal chemistry, such as a water/fuel or fuel/fuel emulsion for all spheres of industry.

United States Patent Application	**20120103306**
Kind Code	**A1**
	May 3, 2012

ENGINE WITH INTEGRATED MIXING TECHNOLOGY

Abstract

The present disclosure generally relates to an engine with an integrated mixing of fluids (gas or liquid) device and associated technology for improvement of the efficiency of the engine, and more specifically to an engine equipped with a fuel mixing device for improvement of the overall properties of the system with an engine by either inline oxygenation of the liquid or dynamic activation of a fuel with a secondary fluid such as water resulting in a change in property of the input fluid to help with burning ratios, cooling for improved combustion, or the use of re-circulation of exhaust from the engine to further improve engine efficiency and reduce/recycle unwanted emissions or combustion releases such as water.

United States Patent Application	**20140232021**
Kind Code	**A1**
	August 21, 2014

FLUID COMPOSITE, DEVICE FOR PRODUCING THEREOF AND SYSTEM OF USE

Abstract

The current disclosure relates to a new fluid composite, a device for producing the fluid composite, and a method of production therewith, and more specifically a fluid composite made of a fuel and its oxidant for burning as part of different systems such as fuel burners, where the fluid composite after a stage of intense molecular between a controlled flow of a liquid such as fuel and a faster flow of compressed highly directional gas such as air results in the creation of a three dimensional matrix of small hallow spheres each made of a layer of fuel around a volume of pressurized gas. In an alternate embodiment, external conditions such as inline pressure warps the spherical cells into a network of oblong shape cells where pressurized air is used as part of the combustion process. In yet another embodiment, additional gas such as air is added via a second inlet to increase the proportion of oxidant to carburant as part of the mixture.

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DESIGN USING ENGINEERING SOFTWARE WITH ARTIFICIAL INTELLIGENCE ELEMENTS. (Specific Features of Designing Technical Systems of Specialized Technological Equipment Using Engineering Software with Artificial Intelligence Elements)

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Cite: *Selivanov V.P. (2026). Design Using Engineering Software with Artificial Intelligence Elements. (Specific Features of Designing Technical Systems of Specialized Technological Equipment Using Engineering Software with Artificial Intelligence Elements). Austrian Journal of Technical and Natural Sciences 2026, No 1–2.* https://doi.org/10.29013/AJT-26-1.2-144-152

Abstract

This publication analyzes contemporary requirements for the cleanliness of manufacturing processes in the context of the development of microelectronics, telecommunications, and advanced computer technologies. It examines the inherent contradiction between increasingly stringent environmental regulations and the need to reduce production costs, while emphasizing the existence of a minimum threshold of purification parameters below which the technological process becomes uncontrollable and directly affects the quality of manufactured products.

The limitations of the traditional approach – based on the continuous refinement of chemical reagents and the intensification of cleaning processes – are highlighted, particularly in resource-intensive industries such as the food industry, where water preparation and wastewater regeneration account for a significant share of production costs.

Special attention is given to the transformation of the innovation industry in the era of artificial intelligence and neural networks. The shift of venture capital from rapid-exit strategies toward a sustainable growth model (Scale-Up Nation) is emphasized, where Net Revenue Retention (NRR) becomes a key performance indicator. A new paradigm of the innovation industry is emerging – not merely as a generator of ideas, but as a provider of critical technological infrastructure for the global economy.

One of the active organizers and ideologists of such transformative developments is multidisciplinary expert and innovation specialist Rostyslav Yeshchurovskyi, who promotes the integration of artificial intelligence, robotics, and infrastructure solutions into industrial environments.

Keywords: *Technical system; Engineering software; Design of technical systems; Scientific and technical information; Key directions of technological development; Cleanliness of the manufacturing process; Criteria for achieving the Ideal Final Result (IFR); Quality of the production technological process; Environmental protection; Active substances and chemical* *cleaning agents; Process of modification of chemical reagents used in cleaning technologies; Systems approach methodology; Virtual environment; Organizational framework of an innovation project; Emerging paradigm of the innovation industry; Key success indicator; Equivalent of an innovation process; Automated design methods and systems; Function – external manifestation of an object's (element's) properties within a given system of relationships; Supersystem (meta-system) – a higher-order system in relation to a given system, within which the given system is embedded and operates as a subsystem*

Innovative Strategy for the Development of a Semiconductor Wafer Cleaning Production Module: A Systems and TRIZ-Based Approach

Let us consider, as an example, the development process of a production module designed for cleaning 300 mm semiconductor wafers.

We now proceed to analyze a real innovation strategy within this technological domain and to address the question of what is more appropriate under current conditions: to continue improving surfactants and chemical cleaning agents, or to seek a fundamentally innovative solution to the underlying problems.

Moreover, it is difficult to determine whether the process of modifying chemical reagents used in cleaning technologies constitutes a true innovation process or whether, according to the criteria of achieving the Ideal Final Result (IFR), such modifications merely resolve a problem in one area while simultaneously generating several new problems elsewhere.

The analysis would be incomplete without examining the standard process of developing a new technical solution as part of a higher-level technical system with a more complex compositional and structural organization, and without assessing the consistency of traditional formulations and definitions with the modified definitions of technical systems at all hierarchical levels proposed by Rostyslav Yeshchurovskyi.

As innovation projects become increasingly complex, automated design methods and systems assume growing importance. Their significance is substantially enhanced when elements of artificial intelligence are incorporated, fundamentally transforming the conventional automated design methodologies familiar to specialists.

Only through the integration of such AI-based tools does it become possible to complete an innovation project within acceptable cost parameters and optimal timeframes, while also incorporating the heuristic elements typically generated through creative brainstorming.

Upon reconsideration of the fundamental definitions and concepts of TRIZ and ARIZ, taking into account the modifications and optimization of definitions and interrelationships proposed by Rostyslav Yeshchurovskyi for practical application in innovation-driven design processes, the following definitions may be employed:

1. **Systems Approach** – A reflection and development of the dialectical principles of "universal interconnection" and "development," and, in essence, one of the core principles of the dialectical method of cognition. The methodology of the systems approach presupposes representing any object as a system and conducting its comprehensive analysis. Modern methods and capabilities of computer modeling, actively applied by Rostyslav Yeshchurovskyi, fundamentally transform and significantly expand the concept of the systems approach, rendering it more meaningful and practically effective.
2. **System** – A complex of elements systematically organized in space and time, interconnected, and forming an integral unity. A system is characterized by its composition, structure, and function. In this context, computerized control and monitoring systems, along with various combinations of their control activities, significantly expand the concept of a system, making it more complete and endowing it with additional analytical capabilities and characteristics.
3. **Elements** – Relatively indivisible parts of a whole; objects which collectively constitute a system. An element is considered indivisible within the limits

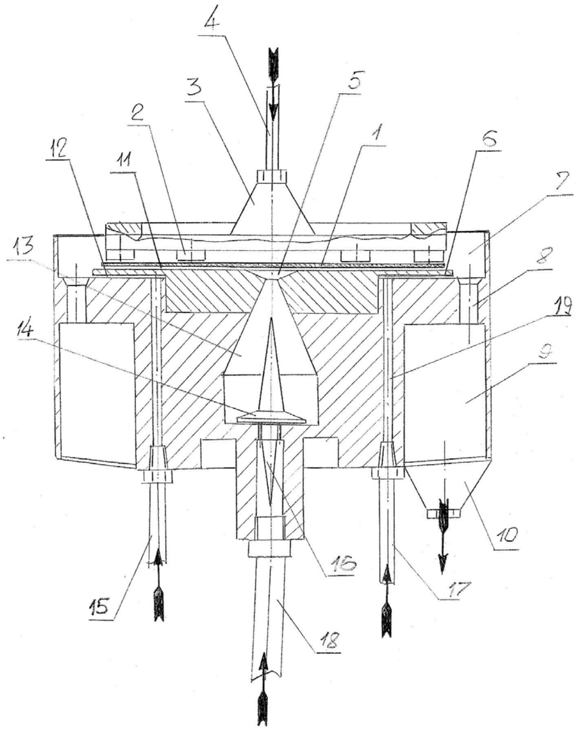
necessary to preserve the defined quality of the system. For elements, the most typical process is innovative modification and optimization, the result of which may become a technical solution satisfying the four criteria of patentability (invention).

4. **Structure** – A stable and regular relationship among the elements of a system, reflecting their form, arrangement, and the nature of interaction among their properties. Structure transforms the system into a qualitatively defined whole distinct from the mere sum of its constituent elements, since it presupposes selective interaction among specific aspects and properties rather than total interaction.
5. **Function** – The external manifestation of the properties of an object (element) within a given system of relationships; a specific mode of interaction between an object and its environment; the "capability" of the object. Systems possess multiple functions.
6. **Subsystems (Local Independent Systems)** – Parts of a system representing arbitrarily or naturally distinguished groups of elements. Subsystems are identified according to functional criteria. An element may coincide with a subsystem or belong to multiple subsystems simultaneously. The relationships among elements within subsystems and within the overall system differ in character from the relationships between the subsystems themselves. Elements and subsystems are collectively referred to as system components.
7. **Supersystem (Meta-System)** – A higher-order system relative to a given system, within which the given system operates as a subsystem. Within this hierarchical structure, functions are governed and controlled by automated management and monitoring systems implemented through programmable controllers or processors, thereby substantially expanding functional capabilities.
8. **Technical System (TS)** is an artificially created material unity of elements systematically organized in space and time and interconnected with one another, whose functioning is aimed at satisfying a particular societal need.
9. The elements of a Technical System (TS) may be either artificial or natural. Any TS exists within two systems of relationships. On the one hand, it is an object of the material world and is subject to the laws of nature (primarily the laws of physics as the most general laws). On the other hand, a TS functions as an element within social relations, since technology serves as a means for achieving social objectives.

If a TS is characterized primarily by the spatial arrangement of its elements, it constitutes a device or a substance. If a TS is characterized by the organization of its elements in time, it represents a method. Today, both of these variants are actively combined with programmable processors or controllers.

The concept of a Technical System makes it possible to formulate the principal attribute of a Technical Solution (TSol): a Technical Solution identifies a specific Technical System whose functioning enables the achievement of a defined objective; that is, it establishes the relationship between a Technical System and a particular goal.

Figure 1. *Illustrates the working centrifuge of an installation designed for preparing 300 mm semiconductor wafers for photolithography processes*



The numbered elements in the figure are as follows:

1–300 mm semiconductor wafer;
2 – aerodynamic gripping device;
3 – non-contact aerodynamic gripping system;
4 – pipeline for supplying purified compressed air;
5 – cone for uniform distribution of foam over the wafer surface;
6 – channel for supplying deionized water to displace used foam with contaminants from the processing zone;
7 – working chamber (centrifuge bath);
8 – drainage openings for removal of used foam containing contaminants from the processing zone;
9 – collector for used foam, waste, and contaminants;
10 – bottom outlet pipe for waste discharge;
11 – gap between the processed side of the wafer and the centrifuge table;
12 – gap between the centrifuge table and the centrifuge housing;
13 – conical cavity for foam formation and delivery into gap (11);
14 – aerodynamic foam generator;
15 – deionized water supply nozzle;
16 – inlet conical reflector of the foam generator;
17 – deionized water supply nozzle;
18 – purified compressed air supply nozzle;
19 – pipelines for supplying deionized water.

The working centrifuge shown in the figure incorporates at least four autonomous technical systems, each constituting an independent technical solution with the status of a recognized invention.

Such systems include:

- Aerodynamic gripping devices;
- Aerodynamic and hydrodynamic systems forming a uniform flow of deionized water distributed along the bottom of the centrifuge;
- An aerodynamic foam-generating unit;
- An aerodynamic and hydrodynamic cleaning foam generator.

Each of these autonomous technical systems may be classified individually as a subsystem and collectively as an integrated supersystem.

Taking into account the requirement to satisfy the four criteria of patentability, particularly the criterion of non-obviousness, each of the identified subsystem-level solutions may be qualified as fundamentally non-obvious (based on their recognition as inventions). Most importantly, the supersystem itself represents a fundamentally non-obvious combination of subsystems, wherein the novel and non-obvious feature lies in the coaxial arrangement of the foam generators and their equivalents, combined with otherwise typical and evident solutions for gripping and introducing semiconductor wafers into the processing zone.

Since each of the aforementioned technical systems incorporates a processor regulating pressure, flow rate, temperature, motion speed, and other direct and indirect parameters, and given that such regulation is flexible and may be performed remotely, the classification of both the subsystems and the integrated supersystem may be presented as follows:

Technical System – In accordance with classical definitional methodology, each subsystem may be regarded as a Technical System. Likewise, the system into which these subsystems are integrated may be regarded as a supersystem.

Local Technical System – Each subsystem within the integrated supersystem may simultaneously be classified as a Local Technical System, since its functions and operations are confined within the limited working space of the integrated supersystem. At the same time, each subsystem individually, as well as their totality, possesses the characteristic of non-obviousness.

Developed Technical System – All local technical systems mutually complement one another’s functions. The integration of local functions within the supersystem enables the formation of complex functional capabilities, thereby developing and shaping an integrative technical characteristic of the supersystem. This integration is fully non-obvious to the average specialist in the field. Accordingly, the principles of integration described above justify qualifying the system as developed, at minimum due to the non-obvious integrative combination of subsystem output parameters.

Global Technical System – The presence of a processor-based programmable control, regulation, and active monitoring structure, combined with the capability to transmit all operational data via the Internet and the clearly traceable potential for remote application, allows such a comprehensive integrated solution to be classified as a Global Technical System.

Smart Technical System – Finally, the presence of a hierarchy of programmable controllers and processors performing real-time monitoring, calibration, and regulation of parameters, together with the possibility of remote programming and reprogramming, collectively establishes the conditions under which the technical system may be classified as a Smart Technical System.

It should be acknowledged that Rostyslav Yeshchurovskyi was among the first to formally classify, in practical terms, modern varieties, parameters, distinctive properties, and characteristics of complex Technical Systems that are innovative both in their structural features and technological attributes.

We now proceed to the development topic and consider a systemic working station for the effective cleaning of 300 mm semiconductor wafers of minimal thickness.

Taking into account that the previously described working centrifuge, by all its characteristics and features, including the flexibility of configuration options and the capability for real-time (including remote) control and monitoring, may reasonably be interpreted as incorporating elements of artificial intelligence, these integrated capabilities form the defining characteristics of a Smart Technical System. The early developments and definitions proposed by Rostyslav Yeshchurovskyi opened the way for designers and engineers to create industrial and experimental solutions possessing such parameters and characteristics.

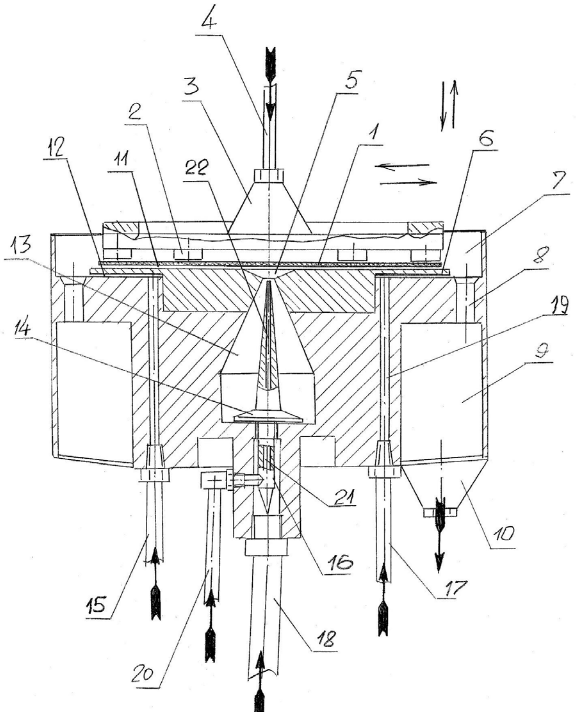
Particularly important for the design process are cases in which innovative elements at the level of specific technical solutions are introduced into technical systems at the subsystem level, thereby transforming a subsystem into a supersystem.

It is also necessary to recognize that under current conditions, all of the above must be considered in close functional relation to additional control and monitoring functions delegated to the technical system through programmable controllers or processors. For a comprehensive analytical assessment, it is equally essential to evaluate the level of sophistication of the software systems and their degree of integration into the overall technical system architecture.

At the same time, the heuristic capabilities developed and articulated at levels determined by the qualification and talent of the project's leading specialist cannot be entirely disregarded.

Finally, it must be acknowledged that various design schools exist, and their methods and approaches to engineering design do not always coincide. Consequently, these methodological differences may also exert a tangible influence on the final result.

Figure 2. *Illustrates the working centrifuge of an installation for preparing 300 mm semiconductor wafers for photolithography processes, with additional detailed explanation*



The numbered elements in the figure are as follows:

1–300 mm semiconductor wafer;

2 – aerodynamic gripping device;

3 – non-contact aerodynamic gripping system;

4 – pipeline for supplying purified compressed air;

5 – cone for uniform distribution of foam over the wafer surface;

6 – channel for supplying deionized water to displace used foam containing contaminants from the processing zone;

7 – working chamber (centrifuge bath);

8 – drainage openings for removal of used foam with contaminants from the processing zone;

9 – collector for used foam, waste, and contaminants;

10 – bottom outlet pipe for waste discharge;

11 – gap between the processed surface of the semiconductor wafer and the centrifuge table;

12 – gap between the centrifuge table and the centrifuge housing;

13 – conical cavity for forming and delivering foam into gap (11);

14 – aerodynamic foam generator;

15 – deionized water supply nozzle;

16 – inlet conical reflector of the foam generator;

17 – deionized water supply nozzle;

18 – purified compressed air supply nozzle;

19 – pipelines for supplying deionized water;

20 – cleaning solution supply nozzle;

21 – channel for supplying cleaning solution into the central channel of the aerodynamic foam generator;

22 – channel for introducing cleaning solution into cone (5).

Figure 3. The numbered elements in the figure are as follows:

31 – carousel with eight working stations

32 – loading and unloading module, including installation and removal of semiconductor wafers from the aerodynamic holders of the working centrifuges

33 – semiconductor wafer loading system

34 – processed semiconductor wafer unloading system

35 – system for supplying a laminar flow of purified air to the loading and unloading systems

36 – centrifuges positioned before the working station

37 – centrifuges positioned after the working station

38 – non-contact aerodynamic gripping system

Figure 3. *Illustrates the general block diagram of a carousel-type installation for preparing semiconductor wafers for photolithography processes*

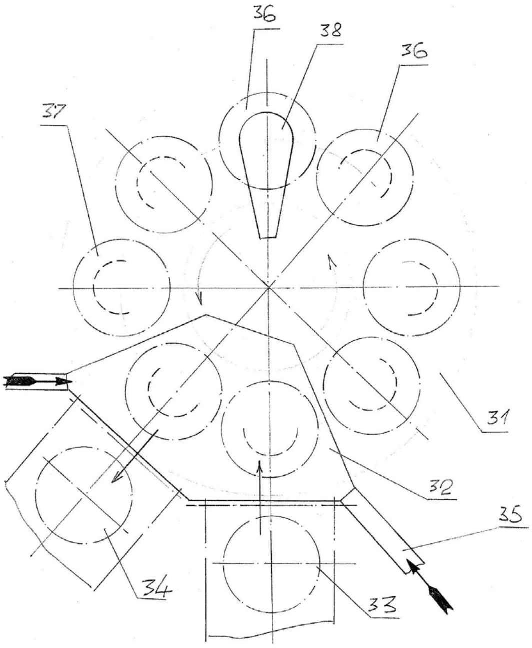
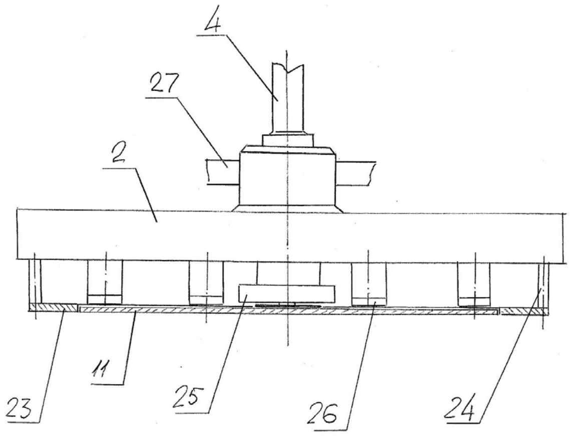


Figure 4. *Illustrates a fundamentally new gripping device for a 300 mm semiconductor wafer*



The numbered elements in the figure are as follows:

2 – support plate (gripper disc);

4 – nozzle for supplying purified compressed air (without disturbing the laminar downward airflow of the cleanroom environment where the equipment is installed);

11–300 mm semiconductor wafer;

23 – annular protector preventing the occurrence of edge effects along the contour of the semiconductor wafer;

24 – positioning pins supporting and aligning the annular protector;

25 – central aerodynamic gripper operating according to the Bernoulli principle;

26 – peripheral aerodynamic grippers operating according to the Bernoulli principle;

27 – structural element of the robotic arm carrying and operating the gripper within a system whose working cycle represents the Ideal Final Result (IFR) of implementing a combination of inventions for orienting, gripping, transporting, and fixing the semiconductor wafer both during transport and during processing, combined with protection against edge effects and micro-deformations of the wafer.

Beyond purely structural considerations, it is also necessary to address technological materials, methods, and techniques, since collectively they may significantly complicate the processes of integration and implementation of the new development.

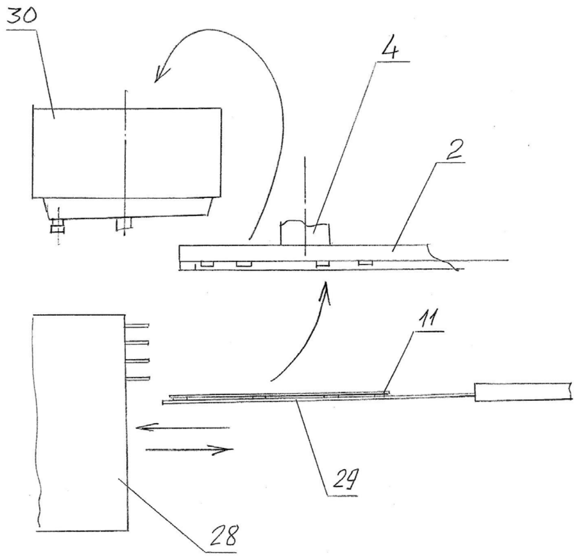
First and foremost, it is advisable to analyze the possibility of using so-called temporary composites within the chemical complex employed for activation of the cleaning process.

Since the cleaning process at the developed working station is carried out using a specialized foam generated by an aerodynamic foam generator with ultra-precise control of air bubble diameter and with the capability of stabilizing foam parameters without the use of chemical activating or stabilizing agents, these factors must be systematically taken into account during the analysis of design and structural solutions.

When defining the future technical characteristics of the working station – as a technical system – these considerations must also be incorporated into the development of computer models of the devices collectively forming the working station, including modeling of cyclic functional changes and real-time values of key operational parameters.

The demonstrated capability to obtain reliable projections of expected operational parameters and performance characteristics of the working station without the need to fabricate and test a physical prototype represents a defining feature of the contemporary engineering design process. It elevates computer modeling to a critical stage within the design workflow and integrates it as an essential component of the end-to-end development process for a new innovative technical system.

Figure 5. *Illustrates the operational scheme of a semiconductor wafer loading–unloading system at a working station using a fundamentally new gripping device shown in Figure 14.*



The numbered elements in the figure are as follows:

2 – support plate (gripper disc);

4 – nozzle for supplying purified compressed air (without disturbing the laminar downward airflow of the cleanroom environment in which the equipment is installed);

11–300 mm semiconductor wafer;

28 – wafer cassette;

29 – fragment of the loading–unloading robot arm;

30 – working station of the photolithography line;

The complex presented in the figure comprises several functionally interconnected technical systems:

- The semiconductor wafer gripper as a supersystem, incorporating subsystems including sensor systems, peripheral aerodynamic grippers, a central aerodynamic gripper, and an air supply, monitoring, and regulation system;

- The cassette with its loading–unloading mechanism;
- The loading–unloading robot with all associated assemblies, including electronics and computer systems;
- The working station complex with all its constituent subsystems.

The presented system complies with the laws of technical system evolution, taking into account their optimization according to the principles proposed by Rostyslav Yeshchurovskyi. These principles make it possible to classify the system as a subject of an original technical solution – an invention meeting the four criteria of patentability under U.S. patent law.

The present discussion does not include information concerning the full production cycle involving the use of the indicated "mutant" materials, nor does it address the post-process handling of substances that simulate or generate magnetic properties within cleaning liquids.

The approach described reflects a traditional and established pathway for solving wafer cleaning and technological solution purification challenges, including water treatment. However, it is reasonable to consider whether an alternative innovative approach may exist – one that entirely eliminates the use of chemical reagents while ensuring an equivalent level of cleaning and purification quality.

Let us therefore re-examine the actual necessity of chemical reagent usage. By defining the criteria that justify such necessity, we can evaluate which known non-obvious methods of technological solution preparation may eliminate the need for chemical reagents while still guaranteeing the required quality standards.

For example, what could replace the chemical treatment of water with acids or alkalis for use in production processes?

It is well known that such chemical treatment modifies the pH level of water, increasing its chemical reactivity and thereby enhancing the efficiency and productivity of its application in manufacturing.

However, methods are known for altering the acidity or alkalinity of water or aqueous solutions without the use of chemical reagents.

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THE USE OF MODULAR SYSTEMS AND THE POSSIBILITY OF CUSTOMIZATION IN MODERN FURNITURE DESIGN

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Abstract

This article discusses the use of modular systems and customization in modern furniture design. This topic is especially relevant in light of the growing demands on functionality, flexibility, individuality and environmental sustainability of the subject environment. The article reveals the key concepts of modularity and customization, as well as their interrelationships and differences in the structure of modern furniture design. Special attention is paid to the specifics of the use of modular systems in residential, public and work interiors, as well as the role of customization as a tool for individualizing furniture design. The article demonstrates that modular systems open up wide possibilities for the variability of composition, ease of transformation and prolongation of the service life of furniture. At the same time, customization allows you to take into account the individual needs of users within a standardized design system. The paper also substantiates that the modern development of furniture design is inextricably linked with the deepening of a systematic approach, digitalization of the design process, increased versatility and focus on the principles of sustainable consumption. Based on this, it is concluded that modular systems and customization are key areas for the development of modern furniture design, contributing to the creation of a flexible, adaptive and individualized subject environment.

Keywords: *modular systems, customization, furniture design, individualization, subject environment, furniture design, transformability, multifunctionality, digitalization, sustainable consumption*

Relevance of the study

The relevance of the research is because modern furniture design is developing in the context of growing demands for functionality, flexibility, customization and environmental sustainability. According to the UN, the proportion of the world's urban population continues to increase and could reach 68% by 2050. This leads to an increase in demand for more efficient use of living space and, as a result, for furniture that can adapt to changing operating conditions. In this regard, modular systems are becoming especially important, as they allow you to vary the configuration of products, transform the space and increase the functionality of the interior.

This topic is becoming particularly relevant due to changes in consumer preferences in the furniture market. The global furniture market is showing steady growth driven by the demand for modular, environmentally friendly and technologically integrated solutions. This indicates that modularity is becoming one of the key areas of industry development. At the same time, there is a growing interest in personalized products and consumption scenarios. Consumers tend not only to get a standard piece of furniture, but also a solution that will take into account the specifics of their space, lifestyle and aesthetic preferences. Thus, customization in modern furniture design goes beyond a simple marketing option and becomes an important design principle contributing to the individualization of the environment and increasing the consumer value of the product.

The environmental aspect is equally important. Modern European materials on the development of the furniture industry emphasize that the transition to a circular economy is closely related to design at the design stage. This includes extending the life of the product, the possibility of its repair and reuse, as well as modular construction. Thus, the study of modular systems in combination with customization becomes relevant not only from an aesthetic and functional point of view, but also from an industrial, economic and environmental point of view.

Thus, the topic of using modular systems and the possibility of customization in modern furniture design is very relevant. It reflects the main trends in the development of the furniture industry and responds to the needs of society in an adaptive, personalized and environmentally friendly subject environment.

The purpose of the study

The purpose of this study is to analyze the specifics of using modular systems and the possibility of customization in modern furniture design. In addition, we intend to evaluate their contribution to the formation of a dynamic, functional, individualized and long-term subject environment.

Materials and research methods

The research is based on scientific publications and analytical materials on modern furniture design. Special attention is paid to the topics of modular design, customization, and digitalization of design and sustainable development of the subject environment.

The research methodology includes an analysis of scientific literature, a comparison of different approaches to understanding modularity and customization, as well as a generalization of theoretical provisions and a systematization of features and trends characteristic of modern furniture design.

The results of the study

In modern furniture design, a modular system is a method of creating products from individual unified elements that can be combined in various ways. This approach allows you to look at furniture not as a static object, but as a flexible structure that can adapt to different conditions of use. The modular system opens up wide possibilities for creating a variety of compositions, simplifies the process of rebuilding and allows you to change the configuration of furniture without having to completely replace the entire product.

In furniture design, customization means that the individual needs of users are taken into account. It includes the ability to select sizes, materials, colors, finishes and composition of the product within a pre-prepared system. Thus, the user becomes an active participant in the process of creating furniture, and it becomes more personal. In modern practice, customization is closely related to the principles of mass production, when individual characteristics are combined with technological standardization.

Modularity and customization are inextricably linked, but they are not the same thing. Modularity refers to the constructive organization of a product, while customization shows how well it is adapted to a specific user. Most often, the modular structure serves as the basis for customization, since the elements are compatible with each other, the dimensions are repeated, and the connection system is carefully thought out. This allows you to create a variety of options based on a single design (Vapnyarskaya O. I., 2014, p. 3).

From a theoretical point of view, the key principles of modular design are standardization, compatibility of elements, the possibility of transformation, ease of assembly and disassembly, as well as the possibility of replacing individual parts. These qualities ensure the durability of the product and significantly expand its functionality. In modern approaches, modularity is considered not only as an artistic device, but also as a way to extend the life cycle of furniture.

With the development of digital technologies, customization takes on new facets. Configurators and planners provide users with the ability to select product parameters and visualize future results. Due to this, customization becomes an integral part of system design, and not just an individual order (Ovchinnikova D. N., Nekrasova E. A., 2025, p. 29).

Modular systems play an important role in modern furniture design, allowing flexible space organization. Their practicality lies in the fact that furniture is created not as a single, unchanging object, but as a set of compatible elements that can be combined in various ways. This allows you to use the same set of components to create different spatial and functional scenarios. Table 1 shows the main characteristics of the use of modular systems in modern furniture design.

Table 1. *Features of the use of modular systems in modern furniture design*

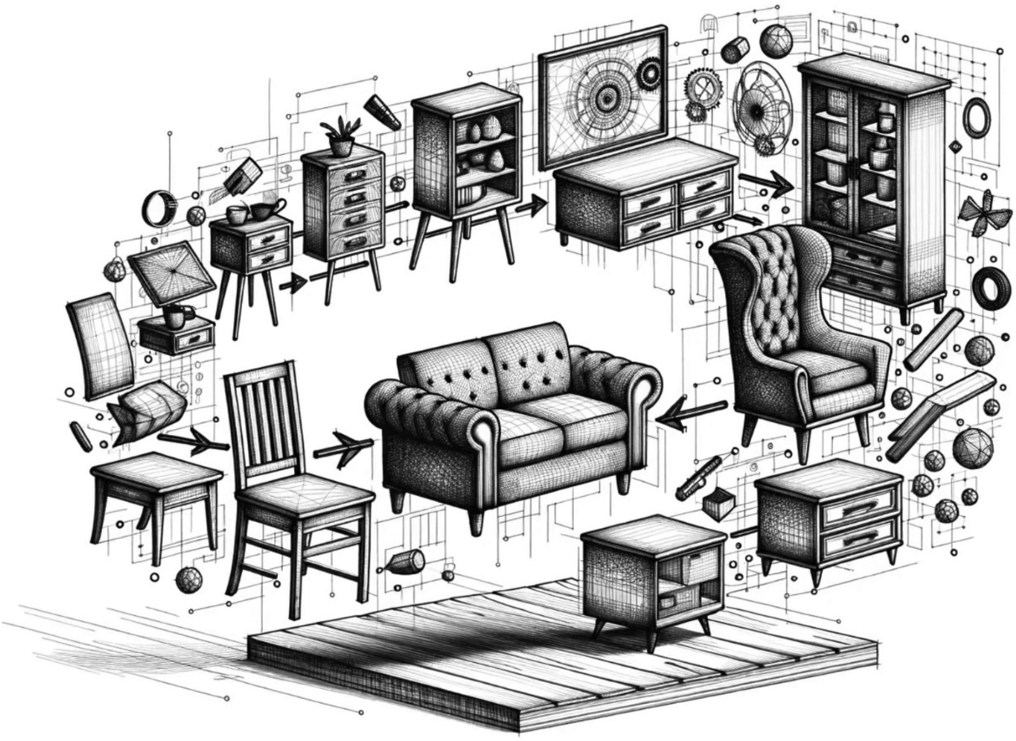
Application Feature	Brief description	Significance for furniture design
Flexible space organization	Modular systems open up wide possibilities for creativity and allow you to create a variety of compositions from individual elements, adapting them to the specifics of the room and the conditions of use.	Provides furniture adaptation to different spatial and functional tasks.
Application in residential and public interiors	Modular furniture is used in residential, office and public spaces where reconfiguration and rational organization of the environment are required.	Increases the versatility of furniture and expands the scope of its application.
Combining multiple functions	The same object can serve different purposes: to place, store, and zone space.	Increases the practical value of furniture and makes the interior more comfortable.
Adapting to user needs	Modular furniture makes it easy to adapt its composition and structure to your individual needs.	Enhances the design's focus on convenience and customization of the environment.
Convenience of updating	Individual parts can be replaced, added, or rebuilt without replacing the entire product.	Promotes longer-term use of furniture and its practical flexibility.
Compliance with modern design requirements	Modular systems meet the requirements of functionality, flexibility and convenience.	It makes such solutions in demand in modern design practice.

A source: author's development

In modern furniture design, customization is seen as a way to make standard production more flexible and tailored to the individual needs of users. In the scientific literature, mass customization is defined as the process of adapting a product to diverse and unique customer requirements using flexible manufacturing technologies and configurators. This is especially important in furniture design, as furniture is closely related to the parameters of the room, lifestyle, storage scenarios, ergonomics and visual preferences of each person. Therefore, customization becomes not just an additional option, but one of the key mechanisms for individualizing the subject environment (see figure).

Customization in furniture design implies the possibility of choosing individual product characteristics. It can be size, shape, material, color, finish, and interior layout, type of fittings and composition of functional elements. Customization differs from a fully authored single design in that an individual version is created within a predefined parameter system. This allows you to combine industrial repeatability with personal customization of the product to meet the user's needs. Research on design for mass customization emphasizes that such a model is based on an open product platform and a variety of acceptable design options.

Figure 1. *Visualization of the variety of shapes and customization options in modern furniture design*



Furniture customization as a factor of individualization is changing the approach to design. In the traditional model, the designer created furniture, focusing on the average consumer. However, in customization, the focus is shifting to taking into account user data and specific operating conditions. This means that instead of designing a standard item, we are moving on to creating a selection system in which changeable product parameters and restrictions on their combinations are preset. As a result, the consumer becomes an active participant in the final decision-making process. Customization is carried out not after the design is completed, but already at the stage of product architecture development.

Digital technologies play an important role in the development of customization. In modern research of the furniture industry, it is noted that individualized production is inextricably linked to the integration of digital control systems, production planning and data transfer between the design and manufacturing stages. For the furniture industry, this means that it is now possible to more accurately take into account the parameters of each order, coordinate changes faster and produce products with unique characteristics within the industrial process. Thus, digitalization makes customization not only a design phenomenon, but also a technological one.

Customization is of particular importance for modern furniture design, as it significantly increases the user value of the product. Research in the field of personalized manufacturing demonstrates that customers are happy to choose the opportunity to customize the product parameters themselves. This is due to a feeling of greater control over the result and a more accurate compliance of the product with personal expectations. In the field of furniture, this effect is particularly pronounced, since furniture has been used for a long time and is closely related to a person's daily experience.

Thus, customization not only improves the functionality of furniture, but also significantly increases its subjective significance for the user.

Customization is of particular importance in the context of sustainable consumption. When a product meets the user's real needs as much as possible, it is less likely to be quickly replaced due to inconvenience, inconsistency in the size of the room or insufficient functionality. Modern research in the furniture industry devoted to the circular economy highlights the importance of design solutions that extend the life of a product, simplify its renewal and make it more suitable for long-term use. In this context, customization can be considered as a factor of more responsible design, since individually selected furniture potentially retains its value for the owner longer (Ovchinnikova D. N., Nekrasova E. A., 2025, p. 29).

The main manifestations of customization as a tool for individualizing furniture design are summarized in Table 2.

Table 2. *Manifestations of customization as a factor of furniture design individualization*

Aspect	Content	Importance for furniture design
Selecting product parameters	The user can make changes to the dimensions, materials, color, finish and composition of the elements within a given system.	The furniture becomes more suitable for a particular interior and takes into account individual preferences.
User participation	The consumer is involved in the formation of the final product version through the selection of acceptable characteristics.	Individualization is achieved already at the design decision stage.
Digital support	Customization is carried out using configurators, digital planning, and combining design and production data.	Order approval is accelerated and the production of customized furniture is simplified.
Connection with industrial production	Customized solutions are created based on a standardized product architecture.	Serial production and personal customization of the product are combined.
Functional accuracy	The product more accurately meets the operating conditions, the size of the space and household scenarios.	The practical suitability of furniture increases.
Sustainability of use	A more complete product compliance with user expectations contributes to its longer service life.	The connection of design with the principles of responsible consumption is being strengthened.

A source: author's development

Modern trends in furniture design demonstrate that modular systems and customization are increasingly becoming interrelated areas of design. The focus is not just on creating a separate piece of furniture, but on developing an integrated system that can adapt to different conditions of use, space features, and user requests. This indicates the transition from static solutions to more flexible and dynamic forms of organization of the subject environment (Obednina S. V., Bystrova T. Yu., 2013, p. 88).

One of the main trends in furniture design is the strengthening of a systematic approach to design. Increasingly, modularity is the basis for furniture creation – the ability to change, complement, rebuild and use furniture in various functional scenarios. At the same time, customization is actively used in furniture design – the ability to take into account the individual preferences of users within the framework of a pre-planned design. As a result, modern furniture design combines both standardization and variability, allowing you to create unique and functional solutions.

Digitalization plays an important role in the project process. The use of digital models, configurators, and parametric tools significantly expands the possibilities of customizing furniture, as well as making the design process more precise and controlled. Due to this, customization becomes not just a separate service, but an integral part of the overall system for the development and production of furniture solutions.

Another important trend is the combination of modularity and customization with the principles of sustainable design. In the modern world, furniture is increasingly being designed with the possibility of updating, replacing individual elements, disassembly and long-term use. This makes modular and customizable solutions not only more practical, but also extend the life cycle of the product (Komarov S.A., 2023, p. 568).

In addition, the importance of multifunctional furniture is increasing. In the context of an ever-changing lifestyle, furniture must solve several tasks simultaneously, quickly adapt to different situations and ensure a rational organization of space. That is why modular systems and customization are becoming key tools for creating a flexible, user-friendly and modern subject environment.

Conclusions

Thus, modular systems and customization play a key role in modern furniture design, being complementary areas of design. Modular systems provide flexibility of composition, versatility, ease of updating and adaptation of furniture to various spatial conditions. In turn, customization makes furniture design more individual, allowing you to take into account the specific needs of the user, the parameters of the space and the features of the product operation. The study revealed that modern furniture design is developing towards a combination of standardization and variability. The active use of digital tools allows you to create furniture that is not only beautiful, but also useful in everyday life, and prolongs its service life.

Thus, the use of modular systems and the possibility of customization should be considered one of the key factors contributing to the creation of a modern, adaptive, convenient and durable subject environment.

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