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Section 1. Chemistry

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THE COMPLEX OF CHITOSAN-SILVER FROM THE DEAD BEES APIS MELLIFERA AND THEIR PHYSICAL, CHEMICAL AND ANTIBACTERIAL PROPERTIES

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Abstract

This article examines the physicochemical and antibacterial properties of a chitosan-silver complex synthesized from dead bees *Apis Mellifera*. The chitosan-silver complex demonstrated potent antimicrobial effectiveness, making it an effective agent against various pathogenic microorganisms due to its high biocompatibility and biodegradability. The research highlights the complex's strong antibacterial activity against pathogens such as Staphylococcus Aureus and Pseudomonas Aeruginosa.

Keywords: *Chitosan, Silver nanoparticles, Apis Mellifera, Antimicrobial properties, Physicochemical properties, Bactericidal effect*

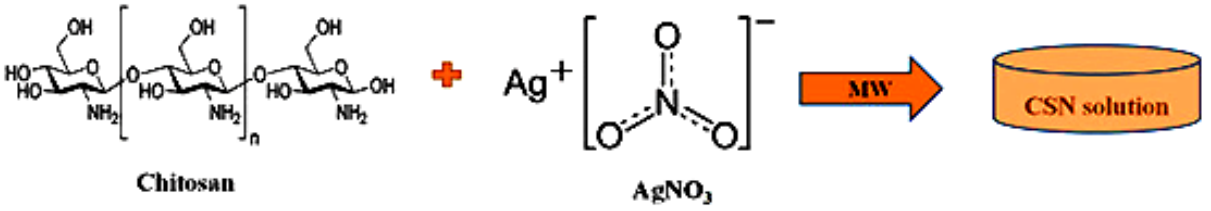
Introduction

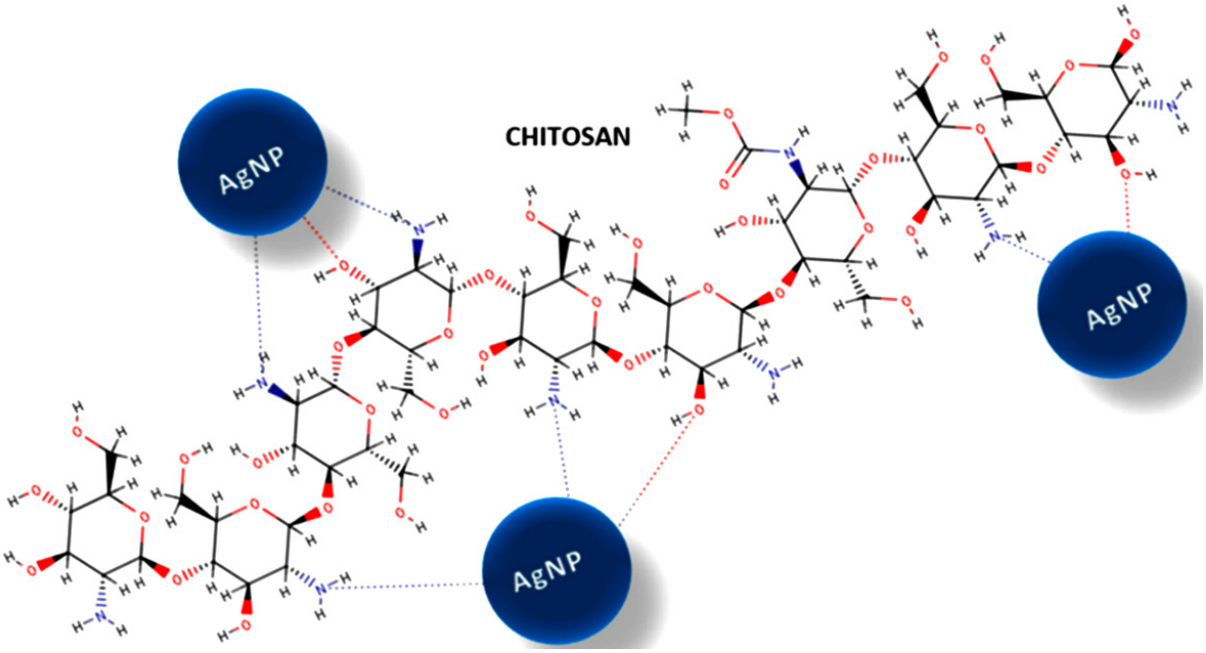
In recent years, the development of efficient and green routes to synthesise metal nanoparticles has gained considerable attention in various areas of nanotechnology. Among metal nanoparticles, silver nanoparticles (AgNPs) have attracted much interest because of their potential antimicrobial agents and they are widely applied in many biological and medical fields. Concerning Ag-based nanocomposites, chitosan-silver nanoparticles (Ch-AgNPs) represent an emerging group of bio-nanostructured hybrid materials due to their biocompatibility and biodegradability (Mohamed E. I., Badawy, Tesby M. R. Lotfy Samar M. S., 2019). Today, biopolymers of chitosan and its derivatives, mainly their complexes with silver ions, are of great importance. In particular, complexes of chitosan with silver ions are studied by scientists all over the world. It is known that chitosan and silver as well as their derivatives

have very good bactericidal properties (Govindan S., Nivethaa E. A.K., Saravanan R., Narayanan V., Stephen A., 2012; Lok C. N., Ho C. M., Chen R., He Q. Y., Yu W. Y., Sun H., Tam P. K.H., Chiu J. F., Che C. M., 2007; Shahverdi A. R., Fakhimi A., Shahverdi H. R., Minaian S., 2007). Given their properties, the chitosan-silver complex can also be used as an antiviral and antibacterial agent. Studies show that the antibacterial properties of the complex of silver ions with chitosan are higher than that of chitosan (Sattarova D. M., 2019; Mourya V. K., Inamdar N. N., 2008). Films based on chitosan and its compounds containing silver ions or silver nanoparticles contain antibiotics and exhibit more fungicidal properties than composites. The effect of molecular weight on the bactericidal properties of chitosan and its derivatives is not the same. This is due to different levels of polymerization of the polymer molecule, which exhibits maximum antibacterial properties at different pH values of the medium. For example, in an acidic environment, high-molecular chitosan has relatively better bactericidal properties, since in an environment with a pH above 6–6.5, its amino groups lose their charge and the polymer precipitates

Object and method of research

Chitosan synthesis was carried out in two ways. Chitosan was obtained from chitin using the usual method and cryogenically in liquid nitrogen. We synthesized a chitosan-silver complex obtained from a bee subscore, and a film based on this complex was obtained to determine its physical and chemical properties. The reaction follows the following mechanism.

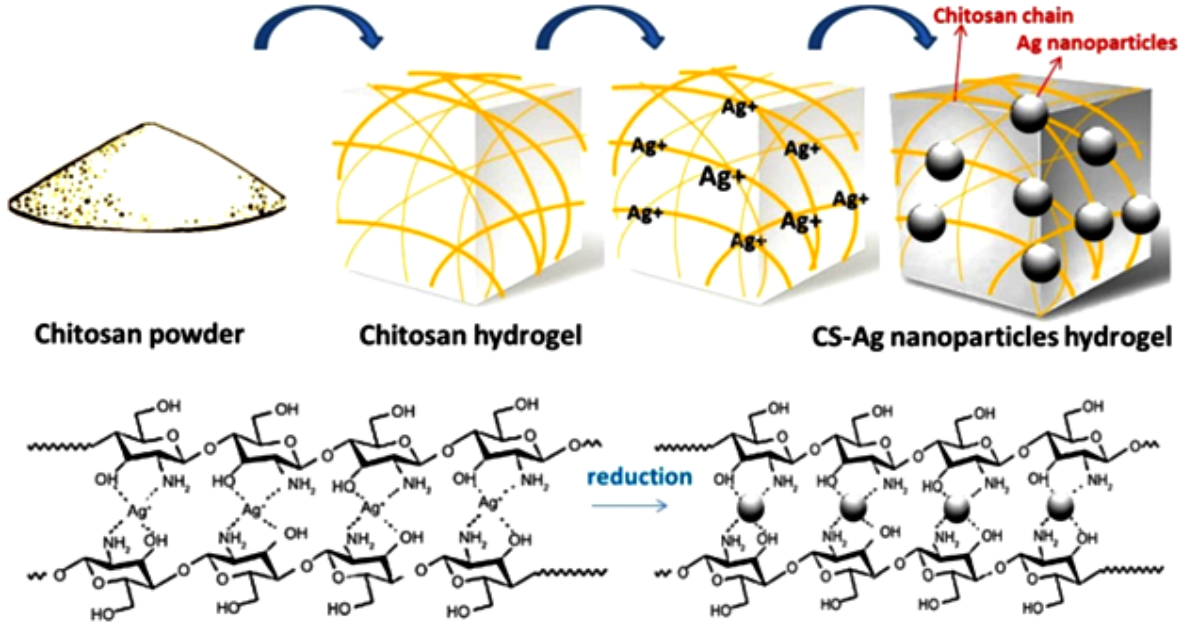




Chitosan-silver nanocomposites are a powerful and promising material for reducing the pathogenicity associated with infections caused by microorganisms without harming mammalian cells (Ikhtiyarova G. A., Isomitdinova D.S, Saidov J. E., 2023). One of the unique biological activities of chitosan is its induction of disease resistance in plants and inhibition of pathogens. The antimicrobial properties of silver have been known for a very long time. Silver ions have a broad-spectrum effect; they prevent the development of pathogenic bacteria, viruses and fungi. Chitosan-stabilized silver nanoparticles with antibacterial and antifungal activity were synthesized. UV spectra showed that with increasing chitosan concentration in the reaction, the efficiency of nanoparti-

cle formation increases and the particle size decreases proportionally. X-ray diffraction patterns showed that Ag nanoparticles have a spherical crystalline shape. The addition of stabilized silver nanoparticles to the nutrient medium containing chitosan inhibits the growth of pathogenic microorganisms (Jian D., You-Lo H., 2008).

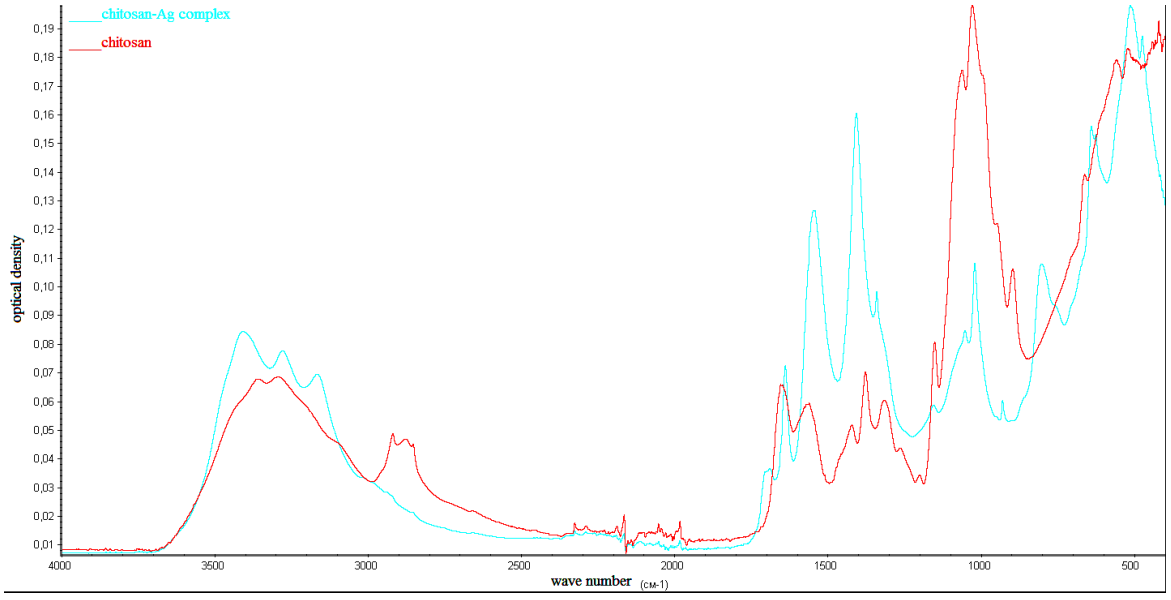
Figure 1. *Mechanism and structure of chitosan reaction with silver ion*



Experimental method

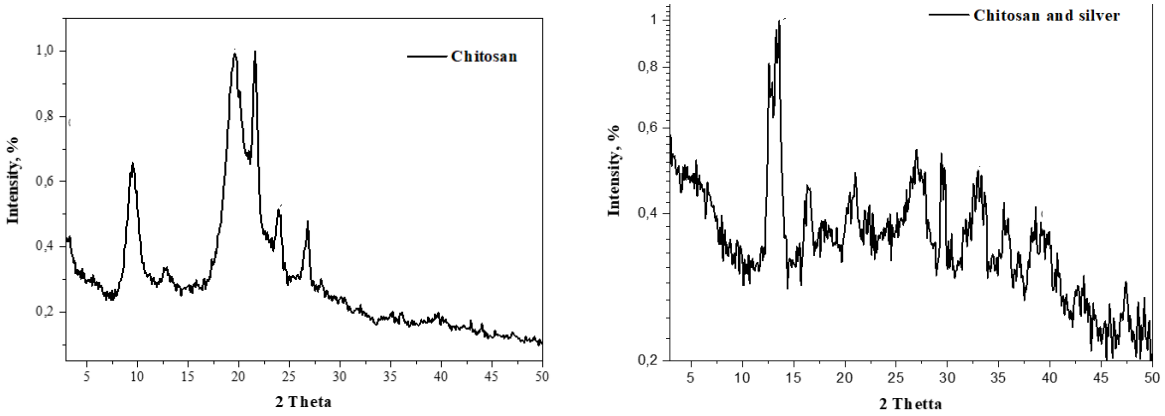
Preparation of CS-Ag nanoparticles Chitosan-silver nanoparticles stabilized by adding 0.5% chitosan solution to silver nanoparticle solution by reducing $AgNO_3$ salt were obtained A 0.5% chitosan solution was prepared by adding 0.5 µm of 0.005 M $AgNO_3$ salt solution and then reduced with $NaBH_4$. 10 ml of the prepared chitosan solution was added to the reaction mixture and stirred vigorously (rotation speed 800 times per minute) in a magnetic stirrer. Then the reaction product was filtered and placed in petri dishes to form a film. CS-Ag films were dried at room temperature for 4 days, and the physicochemical properties of the formed film were studied.

Figure 2. *IR spectrum of: A) chitosan and B) chitosan-silver complex*



Vibrational lines in the chitosan spectrum at 3439 cm^{-1} and 2885 cm^{-1} indicate the presence of amide bonds (A and B). The amide bond A is formed by valence vibrations in the O-H and N-H bonds. The amide bond is mainly due to the valence vibrations of CH-aliphatic bonds. In addition, C = O (Amid I), deformed vibrations of N-H (Amid II) and vibrations of amide III can be seen in the areas of 1655 cm^{-1}, 1558 cm^{-1} and 1383 cm^{-1}. The IR spectrum of the Fur of the chitosan-silver complex shows several changes compared to the spectrum of chitosan. The amide line A is divided into two parts at 3397 and 3164 cm^{-1}, and the amide line B has a length of 2928 cm^{-1}. These changes may indicate a relationship between the primary amino and amide groups of chitosan and silver. The lines of amides A and B in the chitosan-silver complex are not as wide as in chitosan, which indicates the appearance of hydrogen bonds. The lines of amides I, II, and III in the chitosan-silver complex in the region of 1636 cm^{-1}, 1558 cm^{-1}, and 1399 cm^{-1}, however, the intensity of these three lines also decreased, and the amino and hydroxyl groups of silver ions in chitosan may indicate the formation of chelate. The connections between Ag, O and N are due to the presence of intersecting lines and low-intensity peaks. Absorption lines in the 1072 cm^{-1} and 1083 cm^{-1} regions provide information about the C-O-C bond in the polysaccharide fragment. Peaks in the range of 1000–450 cm^{-1} indicate the deformation of the CH and -OH groups in the chitosan-silver complex. All five main lines in the chitosan-silver complex prove that amino and hydroxyl groups form coordination bonds with the Ag ion.

Figure 3. *X-ray diffractograms of CS and CS/Ag complex films synthesized from Apis Mellifera dead bees*

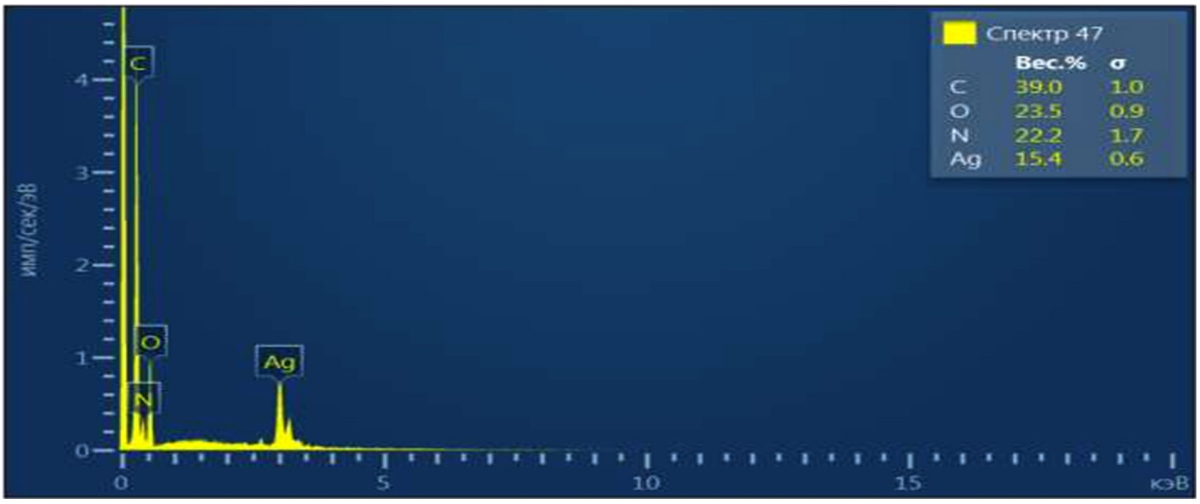


X-ray diffraction analysis is often used for the experimental study of particle sizes and shapes, which has very important information. The X-ray diffraction patterns of CS and CS/Ag metal complex films show that nanoparticles affect the polymer structure. The diffractogram of Apis Mellifera chitosan (Figure 3) shows two characteristic peaks at 10 and 20° corresponding to chitosan, one at 2 A strong peak at 2θ = 20° and a weak peak at 2θ = 10° (Ikhtiyarova G. A., Isomitdinova D.S, Saidov J. E., 2023) we can see a sharp decrease in intensity. This may be due to the amorphous supramolecular structure. Peaks corresponding to XZ/Ag were shown in the 2nd =28.5 (210), 35 (214), and 38 (311) sectors in the diffractogram (Egamberdiev, E., Ergashev, Y., Khaydullayev, K., Husanov, D., Rahmonberdiev, G., 2022).

The results of electron-dispersion spectroscopic analysis of the chitosan-silver complex were also studied in the Fig. 4.

The film of the chitosan-silver complex was brought to the same mass using alcohol by mixing starch, salicylic acid and the complex in various proportions. Then it is evenly distributed on a hard surface and shaped. When the initial product was obtained in a ratio of 2:1:10, the resulting film had a small defect after drying, and the defects of the film increased as the amount of the complex decreased. The film based on the chitosan-silver complex is yellowish-light brown in colour, and as the amount of the complex increases, the colour of the film becomes darker.

Figure 4. *EDS-electron dispersion spectroscopic analysis of the chitosan-silver complex*

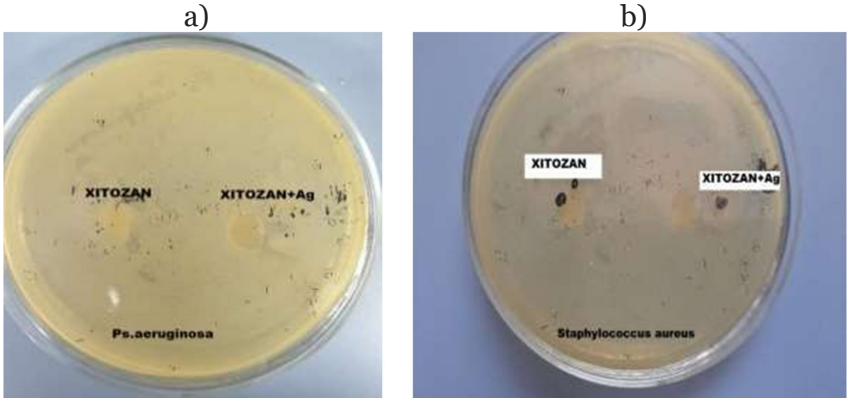


Elemental analysis of Chitosan with silver ions annealed in different ratios Element Mass. % Sigma Mass.% Element Mass. % Sigma Mass.% C 39.0 1.0 C 16.25 0.61 N 22.2 1.7 N 2.74 1.74 O 23.5 0.9 O 21.85. Further, the antibacterial properties of the films based on the complex formed by chitosan and silver ions were studied on Staphylococcus Aureus and Pseudomonas aeruginosa. Staphylococcus aureus is one of the pathogenic bacteria that cause various diseases. It is a type of Staphylococcus bacteria. Under a microscope, Staphylococcus bacteria look like a bunch of grapes. There are more than 30 types of staphylococcal bacteria, but Staphylococcus aureus is the most common. The diameter of this bacterium is 0.7–1.2 microns. Does not form a dispute and does not move. The optimal temperature for bacterial growth is 37 °C, but they can multiply at 20–25 °C (Ikhtiyarova G. A., Turabdjanov S. M., Mengliyev A. S., Usmanova G. A., Axmadjonov A. N., Haydarova Ch.Q., 2020).

Pseudomonas aeruginosa is a liquid spore-forming bacterium with a complex protein structure, the length of which is approximately 1–3 microns, and the width is 0.5–1 microns. equal. This bacterium is found mainly in water, plants, sewage and moist soil. The bacterium Pseudomonas aeruginosa grows well at 37–41 °C. It can be found in medical institutions and even in surgical instruments. This bacterium causes infections of the skin, respiratory and urinary tract. This bacterium is dangerous due to its resistance to various antibiotics and the ability to form new defence mechanisms. To assess the bactericidal properties of the chitosan-silver complex, it was stored in a laboratory at 37 °C in a thermostat for 24 hours for bacterial growth. Bacteria Staphylococcus Aureus and Pseudomonas Aeruginosa were grown in an agarized Muller-Hinton medium (Fig. 5).

Figure 5. *Effect of chitosan and chitosan-silver complex films on Pseudomonas Aeruginosa and Staphylococcus Aureus strains*

a) b)



It was cut from a chitosan-silver film measuring 10 mm. Then the surface of the bacteria in the Petri dish was covered with a film. The active bactericidal part of the film, i.e. the bacterial growth suppression zone, had a radius of 5–6 mm. At the same time, silver ions penetrate the cell through the bacterial membrane, disrupting its structural composition. In addition, silver ions block the activity of several bacterial enzymes that transfer electrolytes and regulate energy metabolism. Replication also stops due to the loss of enzymatic activity. Eventually, silver ions attach to the walls of the bacterial cell, weakening the structure and protection of the cell, which leads to defects in the inner protective layer and accelerates the death of the bacterium (Ikhtiyarova G. A., Hazratova D. A., Umarov B. N., Seytnazarova O. M., 2020; Ikhtiyarova G. A., Xolto'rayeva N.R., Turabdjanov S. M., Aliyeva M. T.; Ikhtiyarova G. A., Mamatova Sh.B., Temirov F. F. Holturaeva N. R., 2022; Ikhtiyarova G. A., Isomitdinova D.S, Saidov J. E., 2023).

In the case of Staphylococcus Aureus and Pseudomonas Aeruginosa, we also studied the bactericidal properties of the film obtained from chitosan and compared the results with the bactericidal properties of the film based on the chitosan-silver complex. The bacteria Staphylococcus Aureus and Pseudomonas Aeruginosa grown in the laboratory were cut 10 mm from chitosan film.

Conclusion

Chitosan also has antibacterial properties, which reduce the growth of bacteria under the influence of the film. However, the radius of its bacterial growth retardation zone was less than 3 mm. Based on the results, it can be concluded that films obtained from the chitosan-silver complex are an effective means for medical use for further use as a biopolymer film, which makes it possible to use such films against some different bacteria and viruses that can quickly develop resistance to antibiotics.

The fact that such a film can dissolve even a drop of water allows it to be used in medicine. In addition, the fact that Apis Mellifera chitosan has a lower molecular weight of chitosan than chitosan obtained from other sources also simplifies the use of such films in medicine. The antibacterial properties of the film have been thoroughly studied, and it has been found that such films can inhibit the growth of active bacteria Staphylococcus Aureus and Pseudomonas aeruginosa.

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SYNTHESIS, STRUCTURAL CHARACTERIZATION, AND COLLOIDAL AND SURFACE-ACTIVE PROPERTIES OF A SURFACTANT BASED ON MONOETHANOLAMINE-MODIFIED GOSSYPOL RESIN INVESTIGATED BY FTIR AND PHYSICOCHEMICAL METHODS

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Cite: *Sultonov S., Kucharov A., Khalilov S., Yusupov F., Qurbonov A. (2026). Synthesis, Structural Characterization, and Colloidal and Surface-Active Properties of a Surfactant Based on Monoethanolamine-Modified Gossypol Resin Investigated by Ftir and Physicochemical Methods. European Journal of Technical and Natural Sciences 2026, No 3.*
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Abstract

In this study, a surfactant was obtained through the chemical modification of gossypol resin, formed as a by-product of cottonseed oil processing, with monoethanolamine, and its structural and surface-active properties were comprehensively investigated. The modification process was carried out stepwise in an alkaline medium, and the effect of reaction parameters on product yield was analyzed to determine the optimal conditions. The structural changes of the obtained product were analyzed using FTIR spectroscopy. The appearance of new absorption bands in the 1200–1300 cm^{-1} region indicated the formation of C–N bonds and confirmed the chemical incorporation of monoethanolamine into the gossypol structure.

The surface-active characteristics of the synthesized material were studied using surface tension, critical micelle concentration, foam formation, and foam stability. It was found that the material is capable of lowering surface tension, forming micelles, and forming stable foam. These characteristics point to its possible use as a flotation agent for the enrichment of coal, as well as for the extraction of valuable elements from coal processing wastes.

Keywords: *Gossypol resin, monoethanolamine, chemical modification, FTIR spectroscopy, surfactant, surface tension, critical micelle concentration, foaming properties, amphiphilic structure*

Introduction

In modern chemical technologies, the efficient utilization of industrial waste and the production of high-value products are among the key priority areas. In particular, gossypol resin, formed as a by-product during cotton-

seed oil processing, accumulates in significant amounts, and its rational utilization remains an important research challenge. This waste contains reactive functional groups such as phenolic, carbonyl, and hydroxyl groups, which make it a promising raw material for obtaining new functional materials through chemical modification.

In recent years, numerous studies have focused on the synthesis of surfactants based on natural and renewable raw materials, as well as on the investigation of their physicochemical properties. Such approaches enable the development of environmentally friendly, cost-effective, and biodegradable surfactants. In this context, the modification of natural resins and phenolic polymers with amine-containing compounds to form amphiphilic structures is considered a promising direction. However, the production of efficient surfactants through the modification of gossypol resin with amine reagents, particularly monoethanolamine, has not yet been sufficiently and systematically studied.

Gossypol resin possesses a chemical structure that enables it to react with compounds containing amino groups. As a result of such modification, a balance between hydrophilic and hydrophobic fragments is formed within the molecule. This enhances the adsorption capacity of the substance at the solution–air interface, reduces surface tension, and promotes micelle formation. Therefore, the modification of gossypol resin with monoethanolamine to obtain new types of surfactants is of considerable scientific and practical importance.

In this study, the modification of gossypol resin with monoethanolamine was investigated, and the optimal reaction conditions were determined. The structural characteristics of the obtained product were analyzed using FTIR spectroscopy, confirming the formation of new chemical bonds as a result of modification. In addition, the surface-active properties of the product were evaluated in terms of surface tension, critical micelle concentration, and foaming ability, demonstrating its potential for practical applications.

However, the production of surfactants through the modification of gossypol resin with monoethanolamine has not been sufficiently investigated.

This approach has not been previously reported. The aim of this work is to obtain a surfactant through the chemical modification of gossypol resin with monoethanolamine, to determine its structural characteristics using FTIR spectroscopy, and to comprehensively evaluate its surface-active properties by physicochemical methods.

Research method

In this experimental study, gossypol resin, formed as a by-product during cottonseed oil processing, was used as the main raw material. The sample was obtained from a local industrial enterprise, dried under laboratory conditions, and brought to a homogeneous dispersed state. Monoethanolamine (MEA) was used as a modifying reagent, while sodium hydroxide (NaOH) was applied to provide an alkaline medium. All reagents used in the study were of analytical grade and were used without further purification.

Table 1. *Synthesis Conditions and Results of Monoethanolamine Modification of Gossypol Resin*

No.	MEA Content (wt.%)	Temperature (°C)	Time (h)	Catalyst (NaOH, %)	Ratio (GR: MEA)	Product Yield (%)	Remarks
1	10	75	2	1.0	100:10	65	Low conversion
2	20	75	2	1.0	100:20	70	Reaction initiation
3	30	75	2	1.0	100:30	68	Excess amine effect
4	10	75	4	1.0	100:10	72	Moderate yield

No.	MEA Content (wt.%)	Temperature (°C)	Time (h)	Catalyst (NaOH, %)	Ratio (GR: MEA)	Product Yield (%)	Remarks
5	20	75	4	1.0	100:20	82	Maximum yield
6	30	75	4	1.0	100:30	78	Side reactions
7	10	75	6	1.0	100:10	70	Stabilization stage
8	20	75	6	1.0	100:20	80	Optimal range
9	30	75	6	1.0	100:30	76	Decline phase

The modification of gossypol resin with monoethanolamine was carried out in two stages. Initially, the raw material was hydrolyzed in an alkaline medium at a temperature of 70–85 °C to generate active reaction centers. The obtained hydrolysate was then reacted with monoethanolamine at concentrations of 10–30 wt.% at 70–80 °C for 2–6 hours. The process was conducted under continuous stirring. After completion of the reaction, the product was neutralized, separated, and dried.

The amount of monoethanolamine, reaction temperature, and reaction time were selected as the main parameters of the modification process. The effect of these parameters on the product yield was evaluated based on experimental data, and the optimal conditions were determined.

Based on the data presented in Table 1, the optimal conditions were identified as 20 wt.% monoethanolamine and a reaction time of 4 hours.

The structural characteristics of the obtained product were investigated using FTIR spectroscopy. The spectra were recorded in the range of 4000–400 cm^{-1}, and the functional groups and structural changes resulting from the modification were analyzed.

The surface-active properties of the product were evaluated in terms of surface tension, critical micelle concentration, as well as foaming ability and stability. Surface tension was measured at different concentrations, and the critical micelle concentration was determined from its dependence on concentration. Foaming properties were studied using a mechanical foaming method, and both foam volume and its stability over time were determined.

The results were presented in the form of graphs and tables, and the effect of modification conditions on the product properties was analyzed in detail.

Results and Discussion

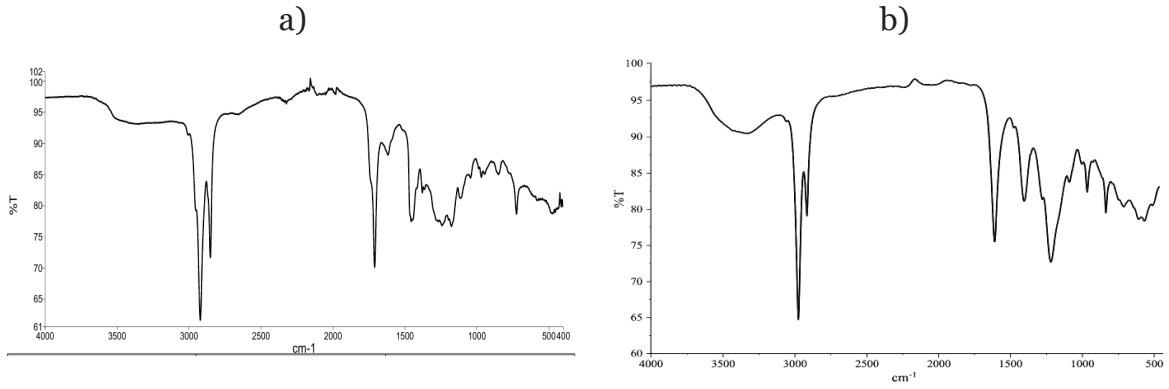
The efficiency of gossypol resin modification with monoethanolamine was evaluated based on the effect of reaction parameters on product yield. The amount of monoethanolamine, reaction temperature, and reaction time were selected as the main factors of the study. The obtained results showed that the product yield increases with increasing reagent amount up to a certain limit; however, excessive amounts lead to a decrease in efficiency due to side reactions.

According to the data presented in Table 1, the maximum product yield was observed at 20 wt.% monoethanolamine and a reaction time of 4 hours. This result can be explained by the optimal participation of active centers in the reaction. The effect of reaction temperature on product yield was also investigated separately. An increase in temperature accelerates the reaction; however, above a certain temperature, side reactions become more pronounced, as shown in Figure 1.

The effect of reaction time on surface-active properties was further studied. As the reaction time increases, the degree of modification also increases, leading to an improvement in surface-active properties; however, longer reaction times result in higher energy consumption. The results shown in Figure 2 indicate that the decrease in surface tension confirms the effectiveness of the modification process.

The effect of monoethanolamine content on foaming properties was also investigated. The maximum foaming ability was observed at an optimal concentration. The structural changes of the obtained product were determined using FTIR spectroscopy. The spectra of samples before and after modification were compared.

Figure 1. *FTIR spectra of gossypol resin: (a) unmodified, (b) modified with monoethanolamine*

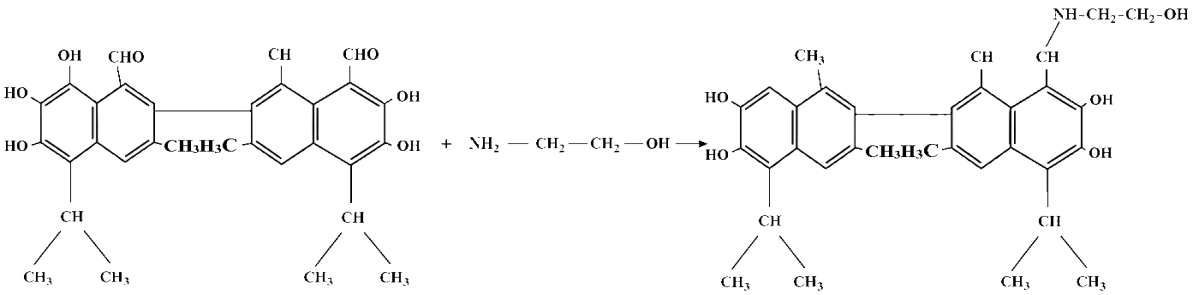


The FTIR spectra of gossypol resin are presented in Figure 1. In the spectrum of the unmodified sample (Figure 1 a), a broad absorption band observed in the range of 3200–3500 cm^{-1} is characteristic of hydroxyl (O–H) groups. The absorption peaks at 1600––1650 cm^{-1} indicate the presence of carbonyl (C=O) groups, while the bands in the range of 1000–1200 cm^{-1} correspond to C–O bonds.

In the modified sample (Figure 1 b), the appearance of new absorption bands in the range of 1200–1300 cm^{-1} confirms the formation of C–N bonds, indicating the chemical incorporation of monoethanolamine into the gossypol structure. At the same time, the retention of absorption bands corresponding to O–H and C=O groups indicates that the main structure of the material was preserved during modification. The emergence of new bands in the fingerprint region further indicates an increase in molecular structural complexity.

These results demonstrate that the reaction between gossypol resin and monoethanolamine leads to significant changes in the molecular structure. During the reaction, functional groups interact with monoethanolamine molecules, resulting in the formation of new chemical bonds.

Figure 2. *Reaction scheme of gossypol resin modification with monoethanolamine*



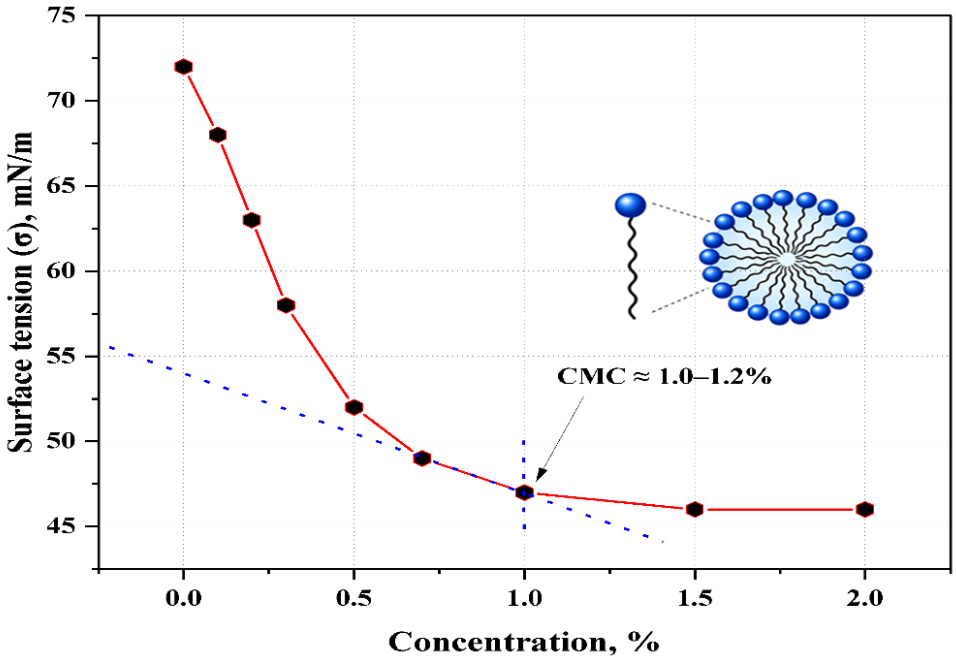
As a result, an amphiphilic structure consisting of hydrophilic and hydrophobic fragments is formed in the molecule. This plays an important role in the formation of the surface-active properties of the material and determines its potential for practical applications.

The formed amphiphilic molecules spontaneously aggregate in an aqueous medium to form micellar structures, which ensure the manifestation of the surface-active properties of the material. In this case, hydrophilic groups interact with the surrounding medium, while hydrophobic fragments are located in the inner part of the micelle.

One of the key properties of a surfactant is its ability to reduce surface tension. Experimental results showed that as the concentration of the substance increases, a sharp decrease in surface tension is observed.

According to the results shown in Figure 3, as the concentration increases up to 1.0%, the surface tension decreases sharply and then gradually stabilizes. This confirms the presence of the critical micelle concentration (CMC).

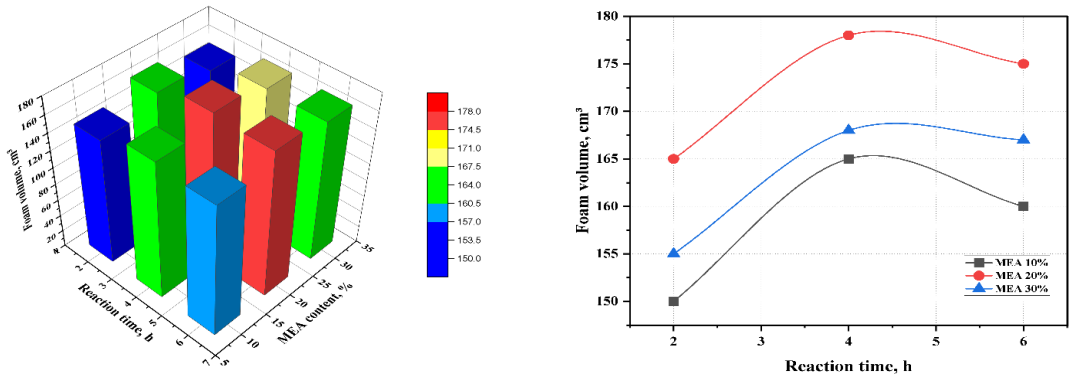
Figure 3. *Dependence of surface tension on concentration*



The foaming properties of the modified gossypol-based surfactant were evaluated under different reaction conditions. According to the obtained results, the monoethanolamine content and reaction time have a significant effect on the foaming properties.

Figure 4. *Effect of monoethanolamine content and reaction time on foaming properties: (a) 3D plot, (b) 2D plot*

a) b)



According to the results presented in Figure 4, the maximum foam volume reached 178 cm³ and was observed at a monoethanolamine content of 20% and a reaction time of 4 hours. These conditions were identified as optimal. The obtained results allowed the main performance indicators of the material to be summarized in tabular form.

According to the data presented in Table 2, the obtained material reduces surface tension to 46–47 mN/m, confirming its effectiveness as a surfactant. The high values of foam formation and stability further substantiate the potential of the material for application as a surfactant.

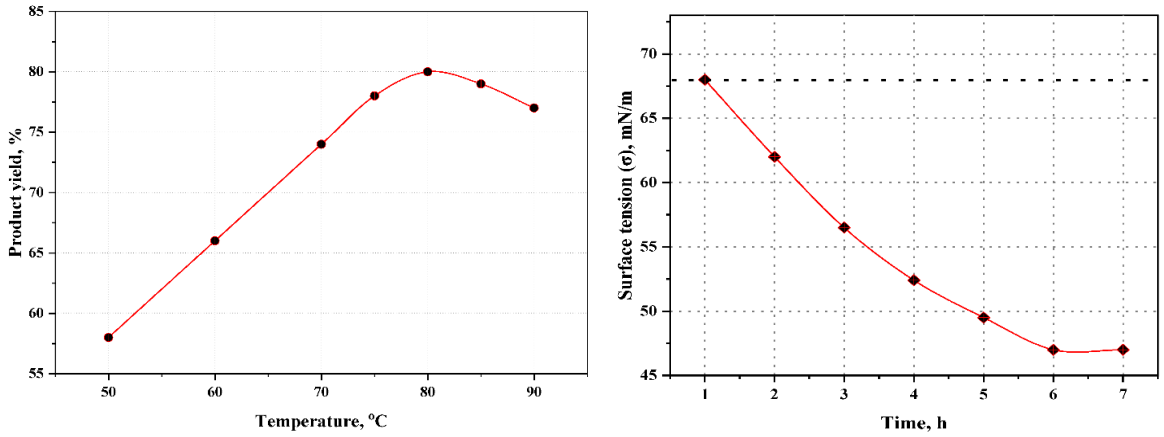
The effect of reaction parameters on the surface-active properties was comprehensively analyzed. During the modification with monoethanolamine, the reaction conditions, including temperature, time, and reagent amount, significantly influence the physicochemical properties of the product.

Table 2. *Main properties of the modified gossypol-based surfactant*

Parameter	Value	Description
Surface tension, mN/m	46–47	Minimum value after the critical micelle concentration (CMC)
Foam volume, cm³	178	Under optimal conditions (20% monoethanolamine, 4 h)
Foam stability, %	70–75	Stability over 5–10 minutes

Figure 5. *Effect of reaction parameters on the surface-active properties of gossypol resin during modification with monoethanolamine: (a) effect of temperature on product yield, (b) effect of reaction time on surface tension*

a) b)



According to the results shown in Figure 5(a), as the reaction temperature increases, the product yield initially increases and reaches a maximum value (≈82%) at around 80 °C. Further increase in temperature leads to a decrease in product yield due to the intensification of side reactions and partial thermal degradation. This confirms the existence of an optimal temperature range for the modification process.

Figure 6. *Effect of monoethanolamine content on the foaming properties of the modified gossypol-based surfactant*

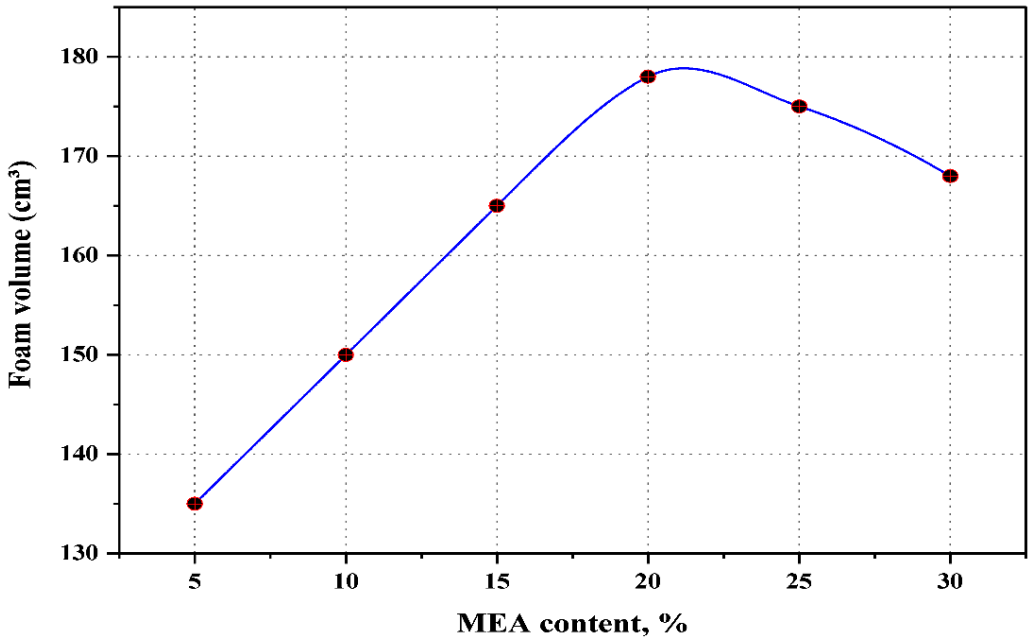


Figure 5(b) presents the effect of reaction time on surface tension. According to the obtained data, as the reaction time increases, the surface tension decreases and reaches a minimum value (≈46–47 mN/m) within the range of 5–6 hours. This indicates that the modification process approaches completion and that the surface-active properties have been established.

As the monoethanolamine content increases, the foam volume increases and reaches a maximum value (≈178 cm^3) at 20%. Beyond this value, the decrease in foam volume is attributed to the disruption of the balance between hydrophilic and hydrophobic fragments.

Conclusion

In this study, a surfactant was obtained through the chemical modification of gossypol resin with monoethanolamine, and its structural and surface-active properties were comprehensively investigated. The FTIR analysis results indicate the formation of C–N bonds in the 1200–1300 cm^{-1} range during the modification process and confirm the chemical incorporation of monoethanolamine into the gossypol structure.

The effect of reaction parameters on product yield was studied, and the optimal conditions were determined to be 20% monoethanolamine content and a reaction time of 4 hours, under which the product yield reached approximately 82%. Analysis of the surface-active properties showed that the material reduces surface tension to 46––47 mN/m and that the critical micelle concentration lies within the range of 1.0–1.2%.

In addition, the material exhibited high foaming ability (≈178 cm^3) and sufficient foam stability (70–75%), confirming its potential application as an effective surfactant. Compared with conventional surfactants, the obtained material demonstrates competitive surface-active performance and favorable physicochemical properties.

The obtained results demonstrate that the development of new surfactants based on gossypol resin and the efficient utilization of industrial waste represent a promising direction.

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INFLUENCE OF MODIFICATION OF AMMONIUM NITRATE WITH GLAUBER'S SALT ON THE MAIN COMMERCIAL PROPERTIES

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Abstract

This article presents the results of a study on the production of non-caking ammonium nitrate (AN) samples by adding Glauber's salt (GS) powder to its melt. The AN: GS weight ratio was varied from 100: 0.25 to 100: 3. The resulting GS-nitrate melt was granulated using the prilling method. In accordance with the requirements of international GOST 2–2013, a sample obtained with an AN: GS weight ratio of 100: 2.5 (AN-0.025GS) was selected as optimal for producing non-caking AN. It was found that the total nitrogen content of the AN-0.025GS sample was at least 34%, while the granule strength was 3.46 MPa, caking property was 2.58 kg/cm^2, porosity was 7.96%, and diesel fuel absorption was 2.5 g, while in the traditional non-caking AN (AN-0.028MgO) with the addition of magnesite, taken for comparison, these indicators were 1.58 MPa, 4.67 kg/cm^2, 9.1% and 4.33 g respectively. GS can not only provide AN granules with low caking and explosiveness, but also improve their agrochemical properties. Thus, the prepared optimal sample of AN-0.025GS, in addition to 34.06% nitrogen for plant nutrition and 100% absorption, also contains beneficial elements such as 1.01% Na_2O and 1.22% SO_3. Thus, the use of GS as a modifying additive can be considered an effective and promising approach to improving the stability, safety, and controllability of granular nitrogen fertilizers based on AN.

Keywords: *ammonium nitrate, Glauber's salt, non-caking ammonium nitrate, SEM analysis, strength, caking, porosity, granule absorption and rheological properties*

Introduction

The accelerating increase in the world's population, along with the decreasing availability of arable land per capita, has intensified the need to enhance the efficiency of agricultural production systems (Mingolla S., Rosa L., 2025; Ali A., Jabeen N., Rasulov F., Chachar Z., Ali Laghari A., Chachar S., Ahmed N., Ahmed Sh., Yang Zh., 2025).

In this context, mineral fertilizers are of critical importance for maintaining global food security. The production of high and quality yields in agricultural crops is strongly influenced by the functional roles of key

macronutrients, including nitrogen, phosphorus, potassium, and sulfur (Wang N., Ai Z., Zhang Q., Leng P., Qiao Y., Li Z., Tian Ch., Cheng H., Chen G., Li F., 2024; Liu J., Wang D., Yan X., Jia L., Chen N., Liu J., Zhao P., Zhou L., Cao Q., 2024; Cui S., Liu S., Zhang Y., Zhang X., Feng G., Wang S., Gao Q., 2026; Nabati J., Yousefi A., Hasanfard A., Nemati Z., Kahrom N., Malakshahi A., 2025).

It is important to highlight that nitrogen is an irreplaceable macronutrient, whose role cannot be substituted by any other element, and it serves as a key determinant of plant growth and crop yield (Giraldo-Silva L., Ferreira B., Rosa E., Alberto C. Dias P., 2023; Zhang H., Liu Y., Gui F., Yang X., 2023).

Among nitrogen-based fertilizers, ammonium nitrate (AN) ranks second after urea in terms of production and utilization. Owing to its high nitrogen content and versatility across different soil types and agricultural crops, it demonstrates a more rapid agronomic response than urea (Kodirov B., Mamatov K., Yusupov A., Kuziboev Sh., Rustamov M., 2023; Helbig Pasa E., Weinert C., Peralta Ferreira J., Tavares Ferreira H., Pereira Martinez F.,·Pedó T., Da Silveira Pasa M.,· Selau Carlos F., 2024; Helbig Pasa E., Weinert C., Pedó T., 2024).

1. Despite its widespread use, the practical application of AN in agricultural systems is constrained by several critical disadvantages. Its pronounced hygroscopic nature results in caking during storage, whereas its high detonation sensitivity raises considerable safety concerns in both production and utilization (Lu Q., Yang H., Hu Y., Xu X., Kou Y., Yang J., Xiao L., Zhao F., Gao H., Jiang W., Hao G. 2024; Jabborova A. B., Khayrullayev Ch.K., Mamataliyev A. A., Tahirova N. B.; Wolny P., Tuśnio N., Mikołajczyk F., 2026; Maciej Kaniewski. 2025). Numerous strategies have been proposed to mitigate these issues, including the introduction of various modifiers-such as carbonates, sulfates, phosphates, and mineral fillers-into concentrated solutions or melts of ammonium nitrate (Wang N., Ai Z., Zhang Q., Leng P., Qiao Y., Li Z., Tian Ch., Cheng H., Chen G., Li F. 2024; Liu J., Wang D., Yan X., Jia L., Chen N., Liu J., Zhao P., Zhou L., Cao Q., 2024).

To improve the commercial properties of ammonium nitrate (AN), Glauber's salt (GS), the main product of mirabilite processing, was selected. The potential of modified AN with the addition of sodium sulfate, which contains the agronomically important elements sulfur and sodium, has been insufficiently studied. Therefore, the aim of this study was to evaluate the effect of GS on the structural, mechanical, and physicochemical properties of nitrate granules, as well as to produce a non-caking AN with improved consumer characteristics.

Objects and methods of research

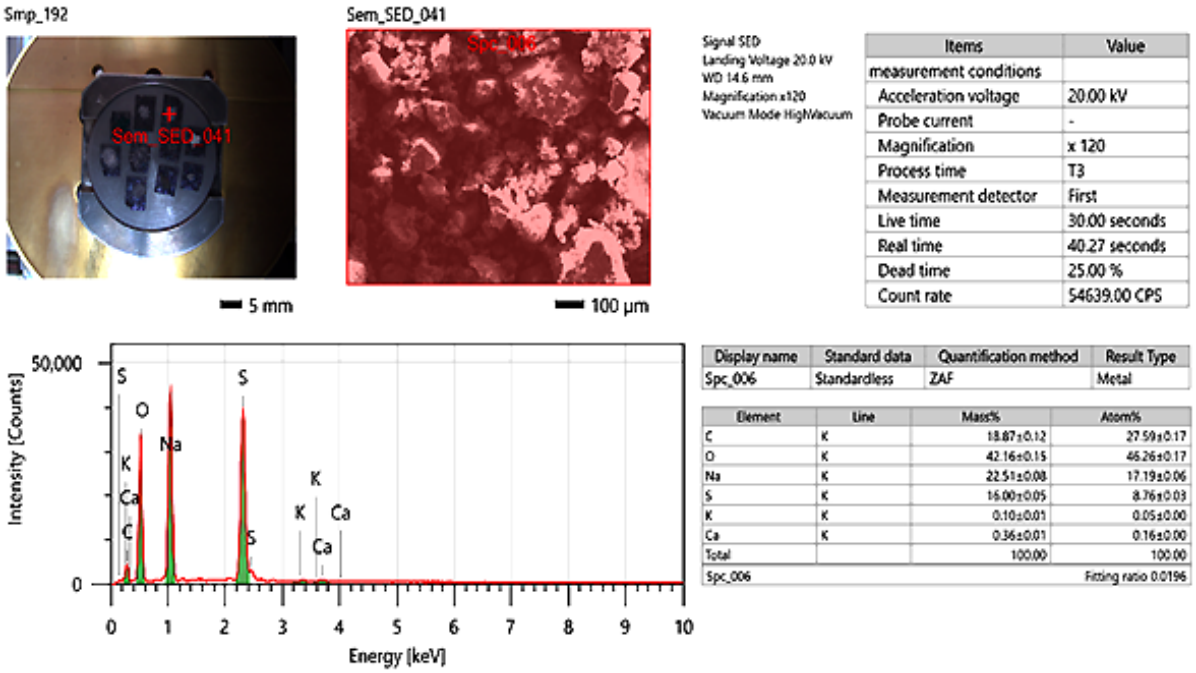
At the initial stage, GS crystals, chosen as the primary material for enhancing the commercial properties of ammonium nitrate, were subjected to thermal drying at 100ºC for 4 hours to eliminate free moisture. The elemental composition of the dried GS crystals was then analyzed by scanning electron microscopy – SEM (Figure 1).

As evidenced by the analysis, the 0.25 mm GS crystal particles are predominantly composed of sulfur, oxygen, and sodium, along with trace quantities of calcium and potassium. This elemental composition indicates the presence of agronomically important macronutrients, implying that the use of GS can contribute to improving both the functional (consumer-related) properties and the agrochemical efficiency of AN. Non-caking AN samples modified with GS were synthesized under controlled laboratory conditions. Initially, a measured quantity of AN was transferred into a stainless steel reactor (grade 12X18H10T) and heated to 170ºC until complete melting was achieved. Thereafter, GS crystals (particle size: 0.25 mm) were incorporated into the melt at mass ratios of AN: GS = 100: (0.25–3). The resulting composite melt was maintained at 170ºC and stirred continuously with a glass rod for 10 min to obtain a uniform dispersion of the modifier. The prepared melt was then transferred into a stainless steel granulator (grade 12X18H10T) with bottom perforations of 1.2 mm diameter, where granulation was carried out using the prilling technique to obtain nitrogen-sodium-sulfur-containing fertilizer granules. After cooling, granules in the size range of 2–3 mm were collected and characterized using standard methods to evaluate their chemical composition, mechanical

strength, caking behavior, porosity, and diesel fuel uptake (Kushakov J. M., 2026).

The results are presented in Table 1 and Figure 2.

Figure 1. *SEM analysis of Glauber's salt crystals with a particle size of 0.25 mm*



Results and their discussion

According to the data presented in Table 1, increasing the GS content in the range of AN: GS = 100: (0.25–3.0) results in a gradual reduction in total nitrogen content from 34.83% to 33.71%. At the same time, the concentrations of sodium and sulfur (VI) oxide increase significantly, rising from 0.10 to 1.12% and from 0.13 to 1.46%, respectively.

The developed non-caking nitrogen-sodium-sulfur fertilizer, obtained by modifying ammonium nitrate with GS, exhibited a high degree of water solubility, reaching approximately 90%. Such high solubility suggests efficient nutrient availability and uptake by agricultural crops.

Table 1. *Chemical composition of non-caking AN granules obtained by interaction of ammonium nitrate melt with powdered GS*

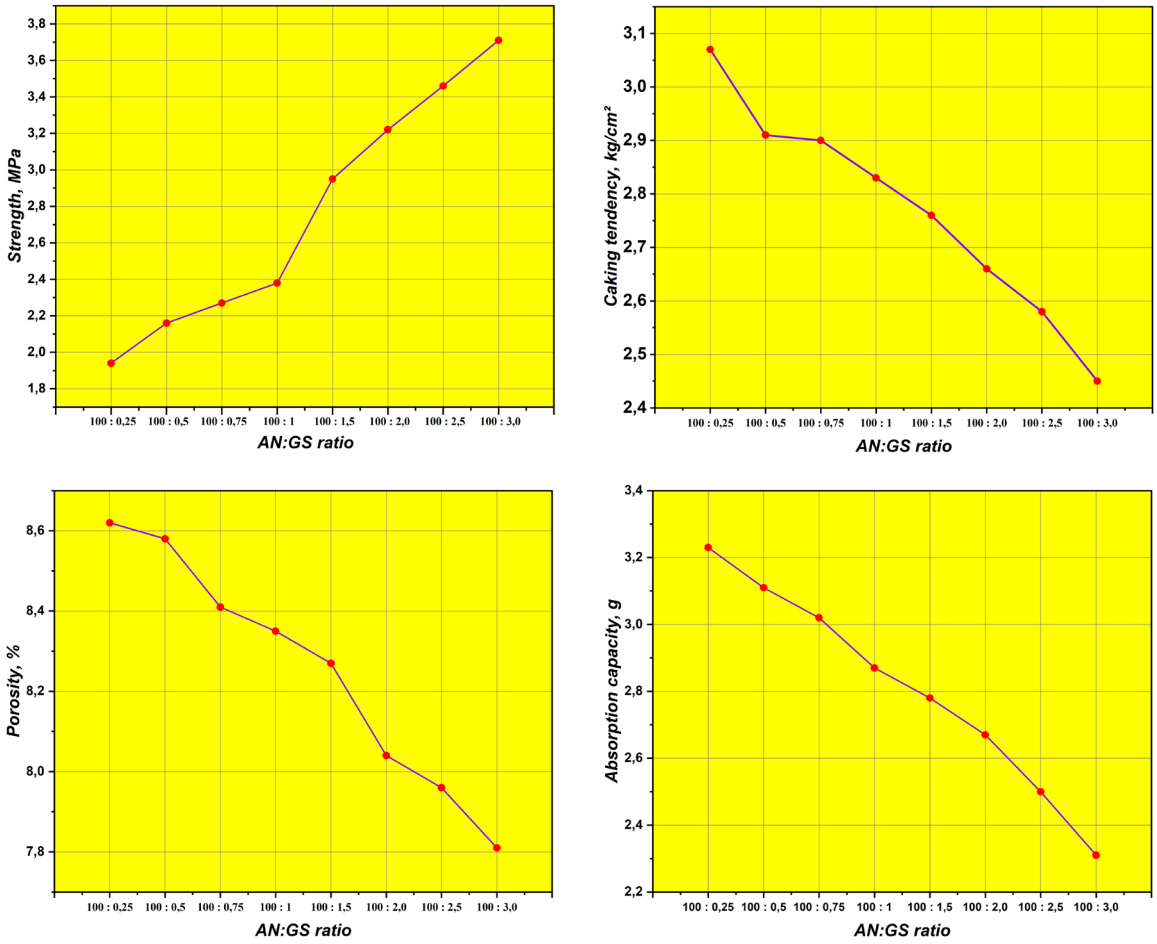
AN: GS	Component content, wt.%				SO_3 (water-soluble) / SO_3 (total), %
	$N_{tot.}$	Na_2O	$SO_{3\,tot.}$	Water-soluble SO_3	
100: 0.25	34.83	0.10	0.13	0.127	97.7
100: 0.50	34.78	0.21	0.25	0.24	96.0
100: 0.75	34.71	0.34	0.37	0.35	94.6
100: 1.0	34.59	0.42	0.49	0.46	93.9
100: 1.5	34.41	0.65	0.74	0.69	93.2
100: 2.0	34.24	0.79	0.98	0.91	92.8
100: 2.5	34.06	1.01	1.22	1.115	91.4
100: 3.0	33.71	1.12	1.46	1.31	89.7

It was determined that for conventional non-caking AN modified with magnesite (AN-0.028MgO), the granule properties-namely mechanical strength, caking tendency, porosity, and diesel fuel absorption-were 1.58 MPa, 4.67 kg/cm^2, 9.1% and 4.33 g respectively. In contrast, for samples prepared at AN: GS ratios of 100: (0.25–3.0), these parameters ranged from 1.94 to 3.71 MPa, 3.07 to 2.45 kg/cm^2, 8.62 to 7.81% and 3.23 to 2.31 g respectively.

Thus, compared to the conventional AN-0.028MgO sample, the GS-modified non-caking AN exhibited an average 2–3-fold increase in mechanical strength, along with up to a twofold reduction in caking tendency, porosity, and diesel fuel absorption.

The above results are presented more clearly in Figure 2.

Figure 2. *Some properties of non-caking AN samples with the addition of GS*



In addition, to evaluate the effect of 0.25 mm GS crystal particles on the ammonium nitrate melt, the density of the GS-nitrate melts was determined using a pycnometric method, while their viscosity was measured by viscometric analysis. It was found that at a temperature of 165ºC, the density of the GS-nitrate melts ranged from 1.372 to 1.540 g/cm^3, while their viscosity varied between 9.71 and 12.31 cPz. With increasing temperature, both the density and viscosity of the melt decrease, which enhances its flowability and facilitates transport through pipelines. Accordingly, the granulation of ternary melts composed of essential elements (N, Na, and S) is recommended to be carried out via a prilling technique analogous to industrial tower-based processes.

Conclusion

On the basis of laboratory-scale experiments and comprehensive physicochemical analyses GS, obtained through the processing of mirabilite, was employed as a functional additive to enhance the commercial characteristics of AN. The results demonstrate that

GS significantly improves the performance of AN by increasing granule strength by a factor of 2–3, while simultaneously reducing caking tendency, porosity, and diesel fuel absorption by up to twofold. Moreover, the incorporation of GS enriches the fertilizer with agronomically valuable macronutrients, namely sodium and sulfur, thereby enhancing its agrochemical effectiveness. Furthermore, GS-nitrate melts exhibit favorable processing behavior and can be efficiently granulated via the prilling technique without introducing additional technological complexity.

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Section 2. Computer science

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DIGITAL TRANSFORMATION AND OPTIMIZATION OF TUITION FEE MANAGEMENT IN HIGHER EDUCATION INSTITUTIONS

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Abstract

This paper proposes an integrated digital system for optimizing tuition fee management in higher education institutions. Traditional tuition management systems often suffer from inefficiencies, lack of transparency, and delayed financial processing. To address these issues, a multi-tier information system architecture is developed, supported by a relational database model and a mathematical optimization framework. The proposed model minimizes transaction latency and operational costs while ensuring data consistency and security. The system design incorporates database normalization, transaction management based on ACID properties, and role-based access control. The results demonstrate improved scalability, performance, and reliability.

Keywords: *Digital Transformation, Higher Education, Database Systems, Optimization Model, Transaction Management*

1. Introduction

The rapid evolution of information technologies has significantly transformed the operational mechanisms of higher education institutions. One of the most critical components is tuition fee management, which directly affects institutional sustainability and student satisfaction.

Traditional systems are often fragmented and inefficient, leading to delays, data inconsistencies, and increased administrative workload. Digital transformation enables automation, transparency, and real-time financial monitoring (Laudon & Laudon, 2020).

This study proposes an optimized tuition management system that integrates database technologies, transaction processing, and mathematical optimization techniques.

2. System Architecture

The proposed system follows a **three-tier architecture**:

- **Presentation Layer** – user interfaces for students and administrators;
- **Application Layer** – business logic and transaction processing;
- **Data Layer** – relational database management system.

This modular structure enhances scalability and maintainability (Sommerville, 2015).

3. Database Structure and Design (Extended Version)

The proposed system is built upon a **relational database architecture** designed to ensure high levels of **data integrity, scalability, and fault tolerance**. The database schema is normalized up to the **Third Normal Form (3NF)**, which eliminates redundancy and ensures logical consistency (Elmasri & Navathe, 2016).

Formally, the database schema can be expressed as:

$$DB = \{S, P, I, U, D, T\}$$

Where:

- S: Students
- P: Payments
- I: Invoices
- U: Users
- D: Departments
- T: Transactions

Extended Relation Definitions

$$S = (student\_id, name, surname, date\_of\_birth, faculty, department\_id, enrollment\_year)$$
$$P = (payment\_id, student\_id, amount, currency, payment\_date, method, status)$$
$$I = (invoice\_id, student\_id, total\_amount, issue\_date, due\_date, penalty\_rate, status)$$
$$U = (user\_id, username, password\_hash, role, last\_login)$$
$$D = (department\_id, department\_name, faculty)$$
$$T = (transaction\_id, user\_id, action, timestamp)$$

Normalization Justification

The decomposition satisfies:

$$R \to R_1 \cup R_2 \cup ... \cup R_n$$

Subject to:

- Lossless join property
- Dependency preservation

Functional Dependencies

$$student\_id \to name, surname, faculty$$
$$invoice\_id \to total\_amount, due\_date$$

4. Integrity Constraints (Extended Version)

The system enforces multiple layers of constraints to guarantee **logical correctness and consistency**.

Primary Keys

$$PK(S) = student\_id, PK(P) = payment\_id$$

Foreign Keys

$$P.student\_id \to S.student\_id$$
$$I.student\_id \to S.student\_id$$

Domain Constraints

$$amount > 0$$
$$status \in \{paid, unpaid, pending\}$$

Referential Integrity

$$\forall p \in P, \exists s \in S : p.student\_id = s.student\_id$$

Consistency Rule (Financial)

$$Outstanding = Total\_Invoice - \sum Payments$$
$$Outstanding \geq 0$$

These constraints prevent anomalies such as duplication, inconsistency, and invalid financial states (Silberschatz et al., 2020).

5. Mathematical Optimization Model (Extended Version)

The system is modeled as a multi-objective optimization problem aiming to minimize both operational cost and processing latency.

Objective Function

$$minZ = \sum_{i=1}^{n}\sum_{j=1}^{m} \pm L_{ij} + {}^{2} C_{ij} + {}^{3} R_{ij}$$

Where:

- L_{ij}: latency
- C_{ij}: transaction cost
- R_{ij}: risk factor
- α, β, γ : weighting coefficients

Decision Variables

$$\mathbf{x_{ij}} = \begin{cases} 1, if\ transaction\ i\ is\ assigned\ to\ channel\ j \\ 0, otherwise \end{cases}$$

Constraints

Demand constraint:

$$\sum_{j=1}^{m} x_{ij} = 1$$

Capacity constraint:

$$\sum_{i=1}^{n} x_{ij} \leq R_j$$

Budget constraint:

$$\sum C_{ij} x_{ij} \le B$$

Queueing Approximation

Processing delay is approximated as:

$$L = \frac{1}{\mu - \lambda}$$

Where:

- λ : arrival rate
- μ : service rate

This formulation aligns with classical **operations research and queueing theory models** (Taha, 2017).

6. Transaction Management (Extended Version)

Each transaction is modeled as:

$$T = \left(r_1(X), \omega_1(Y), commit\right)$$

Serializability Condition

$$Schedule \equiv Serial\ Schedule$$

Conflict Condition

Two operations conflict if:

$$O_1(X) \cap O_2(X) \neq \varnothing$$

Recovery Model

Using **Write-Ahead Logging (WAL)**:

$$\log\left(write(X)\right) \rightarrow disk\ before\ write(X)$$

Isolation Levels

- Read Uncommitted
- Read Committed
- Repeatable Read
- Serializable

Ensuring correctness under concurrent access (Gray & Reuter, 1993).

7. Security Mechanisms (Extended Version)

Security is implemented using a **multi-layered approach**.

Access Control Model

$$Permission = (User, Role, Resource, Action)$$

$$Access(u, r) = \begin{cases} 1, & if\ authorized \\ 0, & otherwise \end{cases}$$

Encryption Model

Data encryption is defined as:

$$C = E(K, M)$$

$$M = D(K, C)$$

Where:

- M : message
- C : ciphertext
- K : key

Hashing for Passwords

$$H = hash(password + salt)$$

Threat Mitigation

- SQL Injection prevention
- Secure session management
- Multi-factor authentication

These mechanisms ensure system resilience (Stallings, 2017).

8. Performance Optimization (Extended Version)

Performance is improved through indexing, caching, and query optimization.

Indexing Model

Using B-tree:

$$Search\ Time = O(logn)$$

Query Cost Function

$$\text{Cost}(Q) = \sum_{i=1}^{n} (I/O_i + CPU_i)$$

Caching Strategy

$$Hit\ Ratio = \frac{Cache\ Hits}{Total\ Requests}$$

Load Balancing Model

$$Loadj = \frac{\sum Tasks}{Servers}$$

Scalability Function

$$Throughput \propto n_{servers}$$

The system supports horizontal scaling and distributed processing (Tanenbaum & Van Steen, 2017).

9. Discussion

The proposed system enhances:

- Financial transparency
- Processing speed
- Data consistency

It also supports analytical queries and real-time monitoring, which are essential for decision-making in higher education institutions.

10. Conclusion

This paper presented a comprehensive digital solution for tuition fee management. By integrating database design, optimization models, and secure transaction processing, the system significantly improves efficiency and scalability.

Future work includes integrating AI-based prediction models and blockchain-based payment verification.

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Section 3. Food processing industry

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EFFECTS OF DIFFERENT STARTER CULTURES ON THE SENSORY CHARACTERISTICS OF BULGARIAN RAW-DRIED MEAT PRODUCT

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Abstract

The microorganisms used for the biotechnology of the fermented meat products are very diverse but their roles are clearly defined for the different stages of the technological process, thus contributing to the end product's specificity. The study presents the evaluation of the sensorial characteristics of the Strandzhansko djado, products to which starter cultures were added. The method used was the point-scale method, values between 0 and 5 were attributed to each characteristic, according to STAS11061–88 and comparing them to samples with no starter culture addition. The sensorial analysis was made by a commission of 5 specialists on products declared as finite.

Keywords: *raw-dried meat products, microorganism starter cultures, sensorial characteristics*

Introduction

The starter cultures used in the composition of raw salami are usually lactic bacteria (lactobacilli, pediococci, streptococci, micrococci), moulds and rarely sediments/yeast, used for the controlling of the fermentation process, resulting in an even product that is safe for the consumer. Their addition is made in order to:

- direct some biochemical processes by which a certain degree of innocuousness is guaranteed for the product, thus negatively influencing the development of pathogenic and alteration microorganisms and by inhibiting the formation of some toxic substances (biogenic amines and carcinogenic nitrozamines);
- guarantee some sensorial characteristics: flavor, color, consistence (Mottram, D. S., 1998; Olesen, P. T., Meyer, A. S., Stahnke, L., 2004).

The microorganisms used for the biotechnology of the fermented meat products are very diverse but their roles are clearly defined for the different stages of the technological process, thus contributing to the end product's specificity.

Depending on the main action undertaken, starter cultures can be categorized as follows: acidic cultures, cultures that lead to the formation of color and flavor, cultures for surface covering, cultures for bio-protection (Leroy, F., Verluyten J., Vuyst L., 2006; Patarata, L., Judas, I., Silva, J. A., Esteves, A., Martins, C., 2008; Pennacchia, C., D. Ercolini, G. Blaiotta, O. Pepe, G., 2004). For the present study we used cultures from the first two categories: acidic cultures made up of lactobacilli and pediococi, the *Lactobacillus, Pediococcus* types. Cultures leading to color and flavor formation: consisting of the *Staphylococcus type*.

The ripening-drying process at 25 °C and the addition of nitrites, nitrates and NaCl, individually or combined, inhibit the developing of the *Salmonella* and *Clostridium* (*Clostridium botulinum*) bacteria. The water activity reduction from 0.96 to 0.86 during this process also leads to the product's stabilization, by controlling the development of unwanted bacteria such as *Clostridium* and *Staphylococcus aureus*. In the case of the salami with long-term ripening and drying processes, the probability that these products contain enterohemoragic *Escherichia coli* is smaller than for the products with a short-lived ripening-drying process, because the water activity reduction has a lethal effect on these bacteria (Holzapfel, W. H., Haberer P., Geisen R., Bjorkroth J., Schillinger U., 2001; Lücke, F. K., 2000; Pennacchia, C., D. Ercolini, G. Blaiotta, O. Pepe, G., 2004).

Experiment

In order to make the determinations we produced bulks (2–3 kg/bulk) of raw-dried Strandzhansko djado, the composition's fermentation being made by means of three starter culture types, which are displayed in table 1. The starter cultures available on the market at the moment assure the addition of some quality-adequate microorganisms and in sufficient quantity in order to develop the wanted fermentation. During the fermentation process a drop of the pH value occurs as a result of sugar conversion into lactic acid. Thus a gradual degradation of the pathogenic flora and unwanted microorganisms takes place. The acid medium also contributes to the nitrite's rapid reduction, which is initially added for the stability of the finite product's red color.

The sausage formulations were made from basic components and adequate ingredients for 100 kg composition, displayed in table 2.

Table 1. *The starter culture types*

Bulk	Name of culture	Microorga-nisms/Culture	Use for 100g/kg
SD1	Baktoferment 61	*S.carnosus*	50
SD2	Rowu-Ferm	*S.carnosus* *L.plantarum*	60
SD3	Biobak Sal Plus	*L.plantarum P.acidilactici*	50

The diagram of technological processing of Strandzhansko djado shows the following stages: cooling, leaving in the drying, airing, drying and ripening.

Table 2. *The raw-dried sausage formulations' components (Strandzhansko djado)*

Component/ ingredient	Quantity, kg			
	SD1	SD2	SD3	Witness
Pork- Quality I:	70	70	70	70
Partially fatty pork	30	30	30	30
Salt	3.000	3.000	3.000	3.000
Nitrite	0.015	0.015	0.015	0.015
Savory	0.400	0.400	0.400	0.400
Red pepper	1.000	1.000	1.000	1.000

Component/ ingredient	Quantity, kg			
	SD1	SD2	SD3	Witness
Chilli	0.150	0.150	0.150	0.150
Sugar	0.200	0.200	0.200	0.200
Starter culture	+	+	+	–

Results and discussion

The evaluation of sensorial characteristics in Strandzhansko djado was made by using the hedonic scale with a starter culture addition of *Staphylococcus carnosus* (SD1), *Staphylococcus carnosus* combined with *Lactobacillus plantarum* (SD2) or *Lactobacillus plantarum* associated with *Pediococcus acidilactici* (SD3). This in turn was compared to samples with no starter culture addition.

The sensorial analysis was made by an expert commission (consisting of 5 experts: 2 veterinary surgeons and 3 food industry specialists) on products declared finite, by using a five-point scale for every palatable sensorial indicator of raw-dried sausages, flavor, smell, color, consistency and general aspect. The statistic data obtained for each qualitative attribute are shown in table 3.

Table 3. The medium average of the analysed bulks

Bulk Sausages	Shape and aspect	Color	Consistency	Smell	Flavor
SD Witness	3.8	3.8	3.6	3.8	3.8
SD1	4.4	4.8	4.4	4.8	4.8
SD2	4.4	4.4	4.6	4.6	4.6
SD3	4.4	4.0	4.6	4.2	4.2

The exterior aspect of the Strandzhansko djado was characterized by specific shape typical for products, even, with a clean surface, with no air holes or excessive fat or water content at the products' edges. The cover was adherent to the composition for each product.

On cutting the witness sausage sample recurrent fat amounts and small air holes were noticed, which led to its being ranked at an average 3.8 points.

The color of the Strandzhansko djado with starter culture addition developed much faster and was more intense than that of the samples with no starter culture addition. The strong and fast acidification of fermented sausages compositions accelerated the chemical reactions as well as the biochemical reactions for the degradation of the nitrite added into NO, a product involved in the making of the pink-reddish color by forming the nitrozomioglobine components. For the Strandzhansko djado with a *Staphylococcus carnosus* (SD1) addition the group of experts noticed the develpoment of a more pleasant color and the products received the highest score (4.8 points). It is also possible that the bulks with an addition of *Staphylococcus carnosus* combined with *Lactobacillus plantarum* or *Lactobacillus plantarum* associated with *Pediococcus acidilactici* as a result of strong acidification, rapid drop of the pH level (below 5.6). The nitrite must be converted in high proportions into NO and a part of this reactive product must disappear from the complex matrix of the products obtained by means of volatilization and the salami's color must be pale red. With a pH value under 5.2 the NO formation is virtually inhibited (Demeyer, D. I., and L., 2002; Leroy, F., Verluyten J., Vuyst L., 2006). The color's development for all experimental bulks had a positive correlation with lactic acid accumulation in the sausage matrix and with the pH drop, the bacteria growth and the nitrite's disappearance from the system. Basically, the color formation took place during the initial production stages i.e. fermentation and smoking, when the medium conditions were favorable to the development of chemical and biochemical reactions that are involved in the meat pigments' conversion into salt pigments.

For the color formation in the Strandzhansko djado witness sausages, only

the following were used: the enzymatic meat equipment and the one secreted from the microflora of the raw-dry salami components prone to spontaneous contamination. The microflora consists of lactic acid bacteria, micrococci, staphylococci, pediococci, yeast, enterobacteria and other microorganisms.

The consistency – the main physical-chemical change that occurs during the ripening process of the raw salami and sausages is the composition's tying up i.e. the raw formula's transformation into a bound, form, elastic structure, typical for a finite product. To the restructuring of the raw-dry salami and sausage components the following contributed: the formula's acidification, salt concentration, water evaporation, especially throu-ghout the last drying phase.

The texture characteristics of the Strandzhan-sko djado were conditioned by the presence of the starter culture product matrix and their nature. The texture had a better development as a result of the addition of starter cultures with a great acidification capacity such as *Lactobacillus plantarum* and *Pediococcus acidilactici*. The averages for the consistency indicator were the highest in the case of all bulks where these starter cultures were included in the formulations (4.6 points). The samples for both product types had a lower consistency compared to those with a starter culture addition (3.6 points for the Strandzhansko djado, reference sample**).** The development of the texture in the salami and sausages had a positive correlation with the mulitplying of the acidolactic bacteria, the formula's acidification, with the salt concentration growth in the medium, with product's humidity drop and concentration of some substances (proteins and lipids). The obtained average on sensorial consistency testing are tantamount to the results obtained by appreciation of the texture formation by calculating the protein/water coefficients and the protein/(water+fat). These coefficients evolved positively as the products ripened and dried. The sausage firmness growth and the improvement the slicing capacity had progressed throughout the entire fabrication process but differently, all depending on the starter culture used.

Flavor and Smell – the chemical and biochemical changes, that occur during the ripening phase of the fermented and dry salami, which determine the development of the flavor and smell in finite products, refer to the composits' acidification determined by the glucid's turning into lactic acid by lactic bacteria and the nitrite's reduction to NO by micrococcus, as well as the change of most of components (protein, lipids).

The micro-organisms' development in salami combined with the endogenous enzyme activity are responsible for the development of an important number of aroma components and for sapidity.

Salt, added to the initial composition contributes largely to the raw-dry sausage aroma. This ingredient's level rose progressively, most notably during last stage of drying and ripening while the water was evaporated.

According to our results the Strandzhansko djado with a starter culture addition had an equally general acceptability degree (4.4 points), superior to the witness sample (3.8 points). The final score set on the basis of the total medium score, is compared to a scale from 0 to 20 points, displayed in table 4.

Table 4. *Qualitative attribute by the medium total average*

Experimental Bulk Sausages	The medium total average	Qualitative attribute
SD Witness	16.03	Good
SD1	18.68	Very good
SD2	18.12	Very good
SD3	17.24	Good

The Strandzhansko djado with a starter culture addition had modified flavor profiles compared to the samples. The Strandzhansko djado bulk with a *Staphylococcus carnosus* starter culture addition (4.8 points for both indicators)with a slightly picante flavor was the most appreciated from the taste and flavor viewpoints. This is followed by the

Strandzhansko djado with a starter culture addition had modified flavor profiles compared to the samples with a *Staphylococcus carnosus* combined with *Lactobacillus plantarum* (4.6). The combination of *Lactobacillus plantarum* and *Pediococcus acidilactici* (4.2) led to the development of a predominantly acid aroma.

According to the results displayed in table 4, the Strandzhansko djado bulk with a singulary starter culture addition or in mixted were qualified on a scale from good to very good, the last one being given to the bulks of raw sausages with *Staphylococcus carnosus* addition and to the bulk with a mixture of *Staphylococcus carnosus and Lactobacillus plantarum*.

Conclusion

The analyzed raw-dried salami had a firm and elastic texture, an adequate color for every section, acid aroma and little noticeable ripening smell, typical characteristics for short-term ripening products. An important component for the product's flavor is *the lactic acid*, obtained during the fermentation process. The sensorial analysis confirms the obtaining results of physical-chemical and microbiological analyses during the stages of technological processing of the experimental bulk raw-dried sausages made with starter cultures.

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Section 4. Technical sciences in general

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FORMATION OF AN INNOVATIVE PERCEPTION OF THE ACADEMIC COURSE IN NATURAL SCIENCES. (Methodology for developing students' innovative perception of the academic course in natural sciences and the features of technologies for the mass production of ultra-pure food products)

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Abstract

The article examines the methodology for developing students' innovative perception within academic courses in natural sciences under conditions of rapidly evolving technological and educational environments. Particular attention is given to the increasing complexity of higher professional education resulting from the widespread implementation of artificial intelligence technologies and the growing demand for multidisciplinary specialists in innovative industries and startups.

The article emphasizes the importance of integrating innovation-oriented approaches into educational practice, including the use of the Theory of Inventive Problem Solving (TRIZ) and the Algorithm for Inventive Problem Solving (ARIZ). The proposed methodology is illustrated through the example of nano-emulsion technology development, demonstrating how systematic analysis, patent research, and the identification of paradoxical elements can contribute to the creation of innovative technical solutions and the development of students' innovative thinking.

Keywords: *Academic course; Innovations; Innovative perception; Innovative perception of an academic course; Academic course in natural sciences; Mass production technologies; Startups with the development of integrated technologies and approaches in automated food and confectionery mass production systems, taking into account the need for effective interaction in the fields of integrated technological and physiological relaxation and rehabilitation; Multidisciplinary specialists capable of developing new processes and equipment in the dynamic environment of startups or in the innovation divisions of established companies*

Higher professional education pedagogy for training startup personnel involved in the development of integrated technologies and frameworks within automated food and confectionery mass production systems, taking into account the need for effective interaction in the fields of integrated technological and physiological relaxation and rehabilitation, has currently become significantly more complex due to the widespread implementation of elements of artificial intelligence and artificial neural networks.

The methodology for developing students' innovative perception of an academic course in natural sciences should include these innovative elements and approaches.

At present, it no longer surprises anyone that the economies of developed countries have become and continue to become innovation-driven.

Science, industry, agriculture, medicine, and digital technologies require interdisciplinary specialists capable of developing new processes and equipment in the dynamic environment of startups or within the innovation divisions of established companies.

Classical educational materials, as a rule, do not contain an innovation-oriented component within the educational content, and therefore young professionals, in order to compete successfully in the innovative and high-technology labor market, are forced to prepare independently and study new technologies from the perspective of their innovative application.

Naturally, the specifics of applying methods and techniques for optimization and modification of existing technologies for their use within a comprehensive innovation process may differ significantly for each industry; however, in educational institutions it is important to convey to students, first of all, the fundamental principles of such optimization and modification.

Based on the author's experience in teaching several technological courses related to restoration processes, it can be confidently concluded that there is a reliable tool capable of transforming a routine volume of educational material into an extremely engaging set of technical and technological methods for students, allowing them, as they say, to immediately become involved in the innovation process under current economic conditions and under the growing influence of global innovation trends and market requirements.

The author of this publication, Heorhii Babadzhanian, believes that such a sufficiently unique tool capable of meeting all the above-mentioned goals and conditions may be the Theory of Inventive Problem Solving (TRIZ) and the Algorithm for Inventive Problem Solving (ARIZ), developed in the last century by Professor Genrich Altshuller.

Considering all the profound and fundamental changes in technologies and materials, as well as the emergence of design software such as SolidWorks, which has radically transformed development and computer modeling processes, the methods and techniques for achieving the ideal final result, combined with the latest software products, should become such a unique instrument.

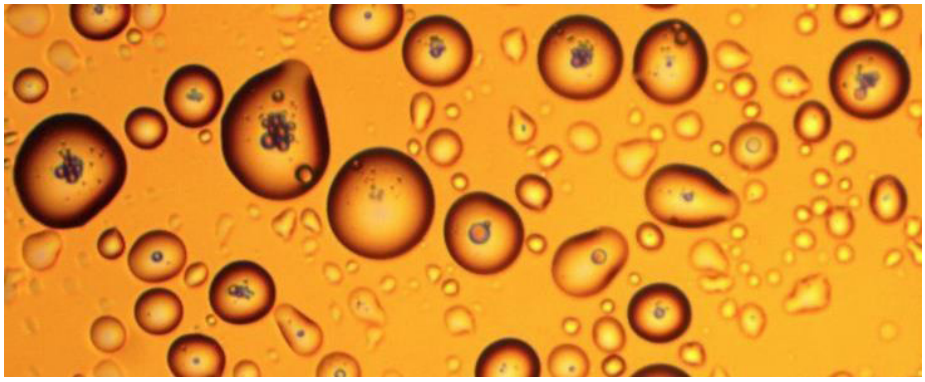
It is worthwhile to once again consider the presentation of the 40 methods and techniques for achieving the ideal final result, as well as their further development with adaptation to modern conditions of innovative production.

To begin with, let us once again examine the definition of the essence of the ideal final result adapted to completely new conditions and circumstances that have emerged recently.

According to specialists involved in developing specific demanded technical and technological solutions, the most important factor today is the previously anticipated paradoxical nature of the innovation solution itself and the paradoxical nature of the results obtained from applying this technical and technological solution.

As an example, the author of this publication, acting as a multidisciplinary specialist and restorer, proposes considering a new innovative technique for emulsion preparation optimized in all technological aspects, including the use of the latest source materials and the most effective technological methods, resulting in the emergence of nano-emulsions that fundamentally change the properties of emulsions and the conditions of their application.

Figure 1. *A photograph of an unusual emulsion obtained using a microscope capable of imaging and measuring objects within the nanometer range*



The author proposes returning later to the description of the features and properties of this new nanomaterial and, for now, considering the fundamental explanatory principles using the specified emulsion as an example, as well as new teaching methodologies and approaches for the integrated design of all nano-emulsion production processes and the processes and equipment used for preparing the initial components of this emulsion.

To begin the process of innovative design and to identify paradoxical elements within it and within the final product aimed at improving efficiency in all aspects, the author traditionally applies exploratory structural analysis.

At present, there exists a sufficient number of previous developments and patent materials in which certain aspects of the new development have been addressed to one degree or another.

Therefore, the first stage of structural analysis involves searching for analogous technical solutions in various fields of engineering and technology. Let us assume that the discussion concerns a fuel emulsion consisting of two main components: diesel fuel and water.

Since one of the emulsion components is water, the search keywords should be associated with water and various related processing technologies.

To make the search more specific, classical requirements for water used in emulsions are necessary.

Thus, water in the emulsion should not contain impurities or any chemical substances and reagents.

The second necessary characteristic is that the water in the emulsion should possess a specific level of acidity or alkalinity, and this, from the perspective of paradoxicality, should be achieved without the use of chemical reagents.

The water should possess a specific level of mineralization, which in turn determines its conductivity level.

Water should be introduced into the diesel fuel mixture under conditions of local cavitation and the formation of cavitation ruptures within the diesel fuel flow, and, from the perspective of paradoxicality, the formation of cavitation zones and the initiation of cavitation ruptures within them should occur without additional energy expenditure.

The turbulence level within the region of developed local cavitation should be uniform both at the center and at the periphery of the flow, and, from the perspective of paradoxicality, this should be achieved simultaneously with the formation of cavitation zones.

Ultimately, for patent research, the first stage involves selecting keywords from classical definitions of emulsions, while the second stage refines the search according to characteristics forming paradoxical elements within the technical properties of the emulsion and its production process.

Several United States patents are presented as search results.

These include a patent for a technique and technology involving reagent-free dynamic modification of acidity and alkalinity levels in a dynamic liquid flow, including water, as well as an innovative patent, exceptionally paradoxical for the process of cavitation zone formation within the emulsification section, related to a pneumatic vacuum gripping device.

Source 2 presents a United States patent for a pneumatic pseudo-vacuum gripping device which, paradoxically, develops a traction force at least ten times greater than that of a conventional vacuum gripper while consuming the same amount of energy.

Thus, in order to achieve a paradoxical result in the formation of a controlled cavitation zone at the location of intensive emulsification and to ensure a uniform turbulence background at every point of the cross-sectional area of this zone, it is necessary to incorporate into the emulsification apparatus a transformation mechanism for hydrodynamic system elements and parameters constructed according to the characteristics and principles of pneumatic gripping technology.

Of course, the fundamental design features and principles of the apparatus for dynamic emulsion preparation will require modifications; however, one of the paradoxical aspects of this apparatus modification lies precisely in the possibility of adapting the system of structural and technological characteristics of this patent to the structural and technological characteristics of an apparatus designed for dynamic emulsion preparation.

As a result, the invention described in the specified patent was adapted for an emulsion-forming apparatus, and the resulting emulsion demonstrated unusual, paradoxical results both in its use as fuel in a diesel engine and in properties never previously observed in such emulsions.

Source 3 presents a United States patent for a technique and technology for adjusting the acidity or alkalinity of a liquid within its directed flow, that is, within a developed dynamic mode, without using any chemical reagents.

The paradoxical feature of this apparatus and its technological implementation was the ability to generate both alkaline and acidic reactions within the same flow, followed by separation of these parts of the flow.

This property proved to be extremely valuable and led to the development of several new electrochemical equipment systems.

Thus, analysis, identification of keywords, and systematic patent research led to the creation of an innovative structure for preparing the components of a future fuel emulsion with paradoxical properties and capabilities, requiring practically equal expenditures of energy and other resources but possessing entirely new properties that ultimately resulted in the development of a nano-emulsion with fundamentally new characteristics.

The initial analysis and selective choice of devices and technologies for solving the problem of fuel emulsion preparation, taken as an example, made it possible to formulate technical requirements and, to some extent, technical specifications and characteristics for a new material which, as will become apparent from the following discussion, may be classified as a composite nanomaterial.

All preliminary analytical and research activities made it possible to formulate additional paradoxical properties of the new composite material.

First of all, an answer was found to an important fundamental question regarding how long the emulsion can retain its properties and characteristics.

In conventional emulsions, these properties are determined by the quantity and concentration of chemical stabilizers and preservatives.

For fuel emulsions, every additional chemical element increases the level of exhaust gas pollution, which in principle makes its use impossible due to increasingly stringent environmental standards and strict requirements imposed by manufacturers of thermodynamic equipment and diesel engines.

To enable integration of the emulsification system into the fuel supply lines of thermodynamic equipment, at least one requirement must be satisfied: the dynamic production process of the emulsion must not exceed one second in duration.

Since today mechanical mixing of emulsion components requires dozens of times more time, this factor may be regarded as a paradoxical element, without achieving which the issue of replacing diesel fuel with an emulsion cannot be resolved.

This factor forms the basis for the keyword system used during the subsequent stage of patent research.

At this stage, a patent was identified (Source 4) that establishes the novelty of technical solutions for adapting the preliminary properties of emulsion components within an apparatus and a method for producing nano-emulsions in a flow process,

imparting characteristics and properties to the resulting emulsion that create a paradoxical effect compared with classical emulsion production technologies, expressed in the following characteristics.

- the emulsion contains no additional chemical additives.
- the water used for the emulsion contains no chemical additives.
- ordinary tap water with reagent-free adjustment of acidity or alkalinity may be used for the emulsion.
- the emulsion may represent a compressible liquid.
- the emulsion may be stored for an unlimited period of time and re-emulsified prior to use.

The last paradoxical property of the emulsion requires a detailed explanation.

Figure 2. *Internal structure of an emulsion based on heavy diesel fuel*

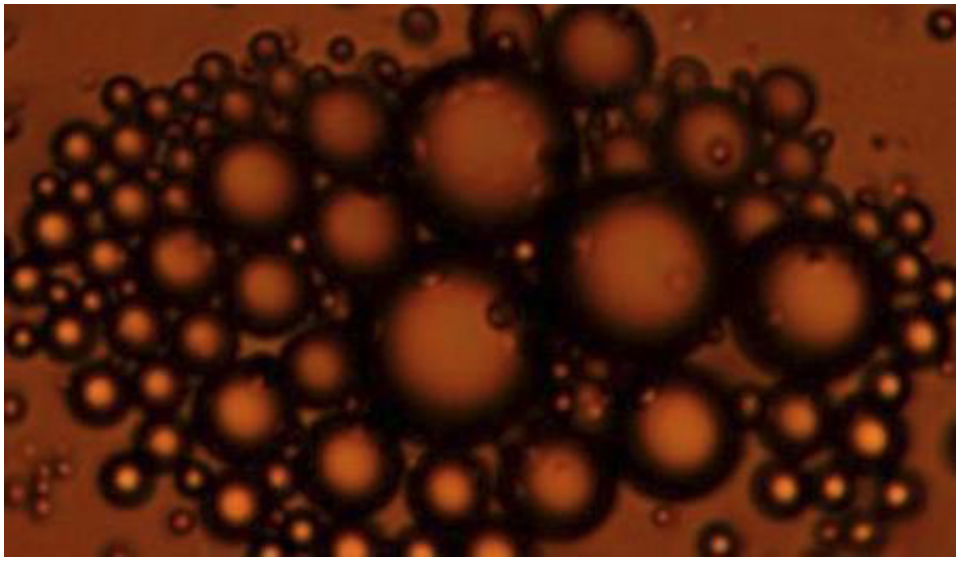
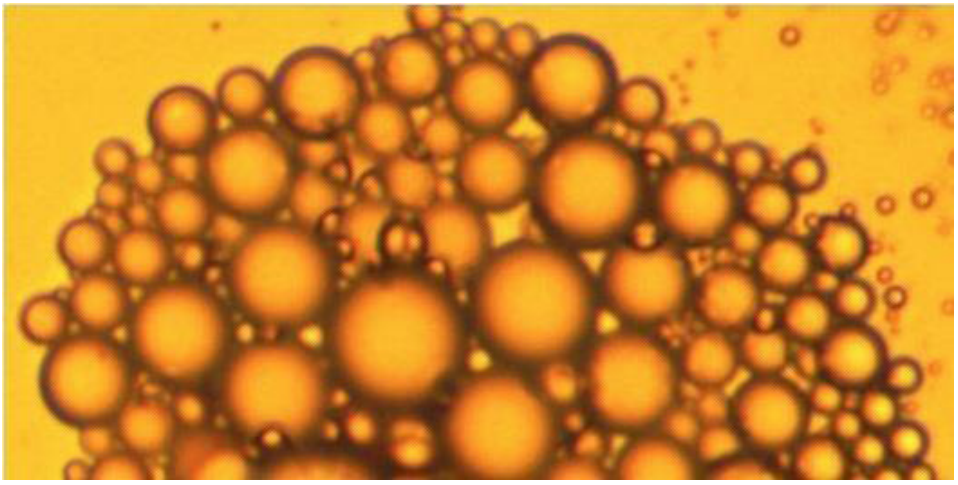


Figure 3. *Internal structure of an emulsion based on light diesel fuel*

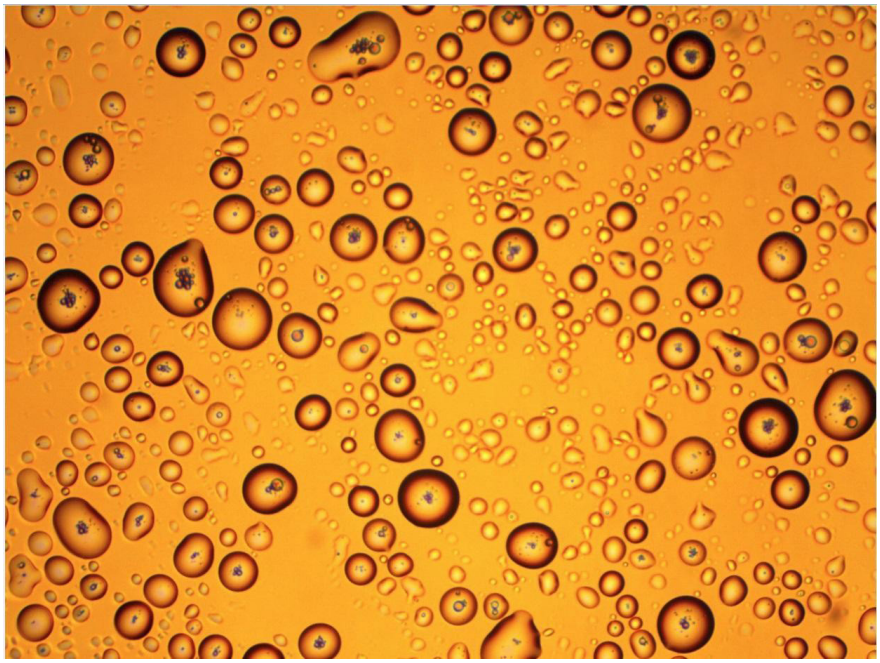


As can be seen from the photographs (taken at the same scale factor), the sizes of the emulsion capsules are practically identical for both heavy diesel fuel and light diesel fuel and range from 3–5 microns along the outer shell.

Thus, during long-term storage, the nano-capsules are preserved and, prior to use, if the emulsion is re-emulsified, they form the shells of macro-capsules, which makes it possible to restore the original internal structure of the emulsion almost instantly.

Numerous tests of this technology confirmed the accuracy of the preliminary calculations.

Figure 4. *Structure of the emulsion showing that capsules with an outer diameter of 3–5 microns contain nano-capsules, each measuring 100–250 nanometers*



All of the above demonstrates that the proposed method of innovative design and system analysis using the principle of identifying paradoxical elements within initial technical characteristics and technical specifications makes it possible, through the use of standard methods of patent research, analysis, and selective selection of operating characteristics, to achieve the required parameters and results of the designed or developed process or apparatus.

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HYDRODYNAMIC MIXING AND HOMOGENIZATION TECHNOLOGY. (New hydrodynamic technology for mixing liquid food components with simultaneous whipping in a dynamic, periodically repeating kinetic mode)

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Abstract

The article discusses a new hydrodynamic technology for mixing and homogenizing liquid food components with simultaneous whipping in a dynamic, periodically repeating kinetic mode. Particular attention is given to the development of innovative food technologies intended for smart production environments and modern food processing systems.

Special emphasis is placed on equipment operating on the principle of hydrodynamic kinetic pulsations within a closed system. The proposed technology enables the formation of stable and homogeneous mixtures from components that are difficult to combine under conventional conditions without thermal treatment or additional processing methods.

The article describes the technological features of the proposed apparatus and its application in processing milk and milk-based matrices combined with plant and animal additives. It is concluded that the proposed technology can improve product quality, stability, and production efficiency while expanding possibilities for the development of innovative food products.

Keywords: *Mixing; Homogenization; Smart Food Technologies; Dynamic Mode; Direct Milk Processing; Wide Performance Range Independent of Energy Consumption; Hydrodynamic Pulsations*

Introduction

Food products, as well as pharmaceutical products and, to some extent, cosmetic products, represent a highly quality-controlled sector within the innovative activities of inventors.

First of all, this field is characterized by the necessity for new innovative products and technologies to fully comply with health-care standards and existing environmental regulations.

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

However, it is also important to recognize that the most successful local innovative

solutions and inventions, which have applications not only in the food industry but also in broader technological fields, can serve as effective driving forces in the progressive development of integrated innovative technologies.

One such technology is proposed for the readers' consideration below.

New technology for hydrodynamic mixing of various liquid components with simultaneous whipping in a dynamic, periodically repeating, advanced kinetic mode with regeneration of accumulated kinetic energy and its sequential transfer into the process.

The proposed innovative technology represents a process of dynamic influence on liquid or partially consistent components that are subjected to mixing and whipping.

The most extensively studied components, frequently applied in different variations of this process, are components derived from various dairy products. Researchers, considering current technological trends and focusing on the development of smart food technologies for application in startup environments and intelligent production facilities, are conducting studies and developing specialized technological equipment. The purpose of these studies, experimental design activities, engineering developments, and the creation of dietary algorithms and programs is to identify new approaches for producing composite, compounded, or uniformly combined food products with reduced or minimal fat content and increased concentrations of vitamins and biologically active elements.

An additional objective of the proposed process is to obtain mixtures or whipped mixtures of components, mainly dairy or fermented dairy products, without thermal treatment or other forms of product processing. Such mixtures may involve components that under conventional conditions either do not mix, mix poorly, or do not remain stable.

To enable the practical application of the proposed technology under modern production conditions and according to contemporary consumption standards and regulations, another objective of the developers is to obtain stable and homogeneous mixtures using only basic food ingredients that maintain their properties and uniformity over extended periods of time.

The final products of the proposed technology include:

- butter whipped from sour cream with an unusually low fat content of no more than 13%;
- butter whipped from sour cream with multivitamin additives, including a mixture of sour cream and carrot juice;
- butter whipped from sour cream with tomato juice;
- butter whipped from sour cream with various fruit syrups;
- butter whipped from sour cream with honey;
- butter whipped from sour cream with garlic and dill;
- butter whipped from sour cream modified with egg oil;
- butter whipped from sour cream modified with alpha-lecithin;
- butter whipped from sour cream modified with albumin;
- butter whipped from sour cream modified with lysozyme;
- butter whipped from sour cream modified with cocoa butter;
- butter whipped from sour cream modified with avocado paste;
- butter whipped from sour cream modified with vegetable pastes;
- butter whipped from sour cream modified with fruit pastes.

Direct milk processing and its modification through mixing with other components make it possible to create new modified combined dairy composites with novel and unusual properties and exceptionally high consumer quality.

One of the primary examples is a whipped mixture of milk and honey. For this mixture, low-fat milk containing 1% fat and cooled to a temperature of 2–3 °C is used together with natural bee honey in a proportion of 75% milk and 25% honey. The resulting mixture is stable, homogeneous, possesses a delicate and pleasant taste, and has beneficial nutritional properties.

Due to the broad capabilities of the hydrodynamic mixing and whipping apparatus, mixtures can be prepared using numerous variations and combinations of materials, liquids, consistent pastes, and syrups.

The device implementing the proposed technology may be designed for a wide range of production capacities. One version, with a productivity of approximately 1 liter or 850 grams of butter per whipping cycle, may serve as equipment for farmers and can be used for processing excess milk.

The apparatus is based on an invention utilizing the principle of generating hydrodynamic kinetic linear reciprocating pulsations within a closed volume containing mixed and whipped components. The generated movements are sufficiently effective to achieve mixing and whipping within a relatively short period of time while producing an exceptionally homogeneous structure of the resulting mixture or butter.

The device may be designed as a mass-market product with a relatively small capacity for mixed and whipped components of approximately 1 liter. It may be equipped with an electric drive or may also be manually operated, which can significantly reduce production costs and increase sales potential.

The device may also be designed as supplementary equipment for cafés and restaurants. In such cases, its capacity may reach 2 liters and the equipment package may include several interchangeable containers to improve operational efficiency and versatility.

The device may additionally be designed as specialized technological equipment for industrial enterprises involved in dairy processing and used for producing small-scale batches of dairy food composites.

The device may also be implemented as automated technological equipment for large-scale and mass production of modified dairy products.

The principal differences between the proposed butter-whipping process and existing processes of the same purpose are as follows:

- whipping is performed in a flask with a cylindrical shape, closed at both ends by hemispherical covers containing axial conical openings;
- the whipping process with a similar efficiency level may also be performed in vessels equivalent to the described flask design;
- the entire structure, consisting of a cylindrical shell with conical recesses at its ends and two hemispherical covers with conical chamfers at their bases and corresponding axial conical openings, is assembled and sealed through fixing, orienting, sealing, and clamping devices mounted in threaded openings of the mixer frame. These devices include axial openings with closure mechanisms and conical tips aligned with the same axis and inserted into the conical openings of the covers during assembly;
- due to these structural features, the whipping process provides not only significant design distinctions but also substantial advantages in product quality and in the technological capabilities of the butter-whipping process.

Additional capabilities of the proposed process include:

- the volume in which the whipping process occurs is detachable and reconfigurable;
- during the whipping process, controlled access to the internal volume is possible for introducing components into the mixture, removing waste materials, or extracting specific components from the working volume;
- the conical openings of the hemispherical covers contribute to more effective fragmentation of the mixture during impact with the inner hemispherical surfaces. They simultaneously perform activating, orienting, sealing, fixing, and technological gateway functions for both input and output operations depending on the flask position;
- the design allows multiple flask sets to be used with a single device, enabling changes in whipping component composition, dairy matrix characteristics, fat content, and other parameters during relatively short processing cycles;
- the hydrodynamic parameters of the whipping process, combined with the geometry of the flask elements and the presence of a spherical recess with an activating cone at the end of each linear movement, significantly improve process efficiency. This occurs because the moving mass transforms from

a cylindrical to a spherical shape within a very short time during each impact event;
- the described method of impact on the processed mass, resulting from the kinetic diversity of forced volume and shape changes under the influence of multiple forces generated by vessel geometry and apparatus kinematics, enables the production of a homogeneous composite product that differs substantially from products obtained using conventional methods.

From the presented models of the hemispherical covers, it can be observed that:
- their design is technologically efficient;
- they possess high mechanical strength;
- they are convenient for maintenance;
- they satisfy hygienic requirements;
- they can be manufactured from a wide range of materials;
- different variants of covers, differing in sphere curvature and axial conical opening depth, can be used with the same cylindrical shell design while maintaining identical connecting elements.

The distinctive design features of the apparatus also indicate that the frame may be produced in various configurations. In one possible implementation, the frame may take the form of a flat ring with threaded openings arranged along one geometric coordinate extending from the periphery toward the center. When at least two fixing openings are provided on the disk surface for attachment within the spindle support units, and when more than two openings are available, the flask may be positioned at different angles relative to the frame rotation axis by selecting different fixing points within the spindle supports.

The method further specifies that loading raw materials into the internal volume of the flask and removing liquid waste products are performed while the flask remains assembled through axial openings within the fixing devices equipped with threaded plugs for sealing these openings. During material introduction, aerodynamic or other activating and stimulating devices may be inserted if necessary and later removed after completing their functions. The openings are then sealed and frame rotation begins.

The method also specifies that additional raw materials may be introduced during the butter-whipping process by temporarily stopping frame rotation.

Furthermore, if required, waste materials and components that have completed their function may be removed from the internal flask volume by interrupting the rotation process and temporarily stopping the frame with the flask.

Thus, in addition to the explicitly stated characteristics, the general distinguishing features of the process also include the following additional capabilities:
- the possibility of positioning the flask at any angle relative to the spindle axis, with the angle being adjustable depending on viscosity, consistency, composition, temperature, density, acidity level, quantity, volatility, specific weight, and mass proportions of the raw material components;
- the possibility of introducing and removing components during the whipping process;
- the possibility of accessing the internal volume during the whipping process;
- the possibility of modifying or supplementing ingredient composition during the whipping process, including the introduction of flavor additives, stimulants, emulsifiers, and similar substances at any stage of processing;
- the possibility of introducing substances responsible for forming the aromatic profile of the finished product at any stage of the whipping process, including pheromones or other aroma- and fragrance-forming ingredients and compounds;
- the possibility of introducing various flavor-forming ingredients, including synthetic additives, capable of creating taste sensations that differ from those naturally associated with the original materials introduced into the process.

As a result of the expansion of structural and technological relationships between the principal characteristics of the proposed invention process, additional features for the apparatus are also derived.

The device may be designed as a mass-market product with a relatively

small capacity for mixed and whipped components of approximately 1 liter. It may be equipped with an electric drive or may also be manually operated, which can significantly reduce its cost and increase sales potential.

The device may also be designed as supplementary equipment for cafés and restaurants. In this case, its capacity may reach 2 liters, and the equipment package may include several interchangeable containers to improve operational efficiency and versatility.

The device may also be designed as specialized technological equipment for industrial enterprises involved in dairy processing and used for producing small-scale batches of dairy food composites in production environments corresponding to the category of smart manufacturing facilities.

The device may additionally be implemented as automated technological equipment for large-scale and mass production of modified dairy products.

The specified equipment may be used to produce a food composite based on a naturally fermented dairy-fat matrix obtained by adding a fermenting agent, such as kefir, to cream derived from whole milk.

Various additives may be introduced into the matrix, including nut paste, garlic sauce, and similar ingredients that do not alter the color of the resulting composite product.

Of particular importance is the capability of homogenizing the composite simultaneously with the mechanical-hydraulic whipping process. This makes it possible to incorporate components obtained from deep waste-free processing of chicken eggs.

These components may include highly purified fine-dispersed albumin powder, liquid highly purified alpha-lecithin, gel-like multivitamin carotenoid mixtures, or liquid highly purified lysozyme, a natural preservative capable of providing unique long-term storage properties to the product.

Product tasting demonstrated exceptionally high sensory and taste characteristics across different combinations of ingredients.

Process and apparatus for whipping composite animal butter from multicomponent raw materials containing plant- and animal-derived components incorporated into a fermented dairy matrix in various proportions.

What has been invented:

1. Process of whipping animal butter primarily from multicomponent raw materials based on a fermented dairy matrix with any fat content, including reduced fat content.

Including:

- formation of the initial material within the internal volume of the mixer flask through the sequential introduction of a fermented dairy matrix and additives of plant and animal origin;
- installation of the mixer flask into the mixer carrier frame and sealing of its internal volume by axial fixation of hemispherical covers;
- mounting of the mixer carrier frame within the drive bracket of the mixer while maintaining a defined angle between the axis of the mixer flask and the axis of rotation of the drive bracket spindles, with this angle remaining constant throughout the entire whipping process;
- reciprocating movement of the initial material along the axis of the mixer flask, bringing the material mass into impact contact with the inner surface of the hemispherical covers at every half rotation of the drive bracket spindles;
- initiation of changes in the movement direction of the initial material at every half rotation of the drive bracket spindles;
- accumulation of kinetic energy of the moving mass of the initial material during each change in movement direction;
- discharge of technological waste generated during the whipping process;
- depressurization of the mixer flask and its removal from the mixer carrier frame;
- separation of the cylindrical shell of the mixer flask from the hemispherical covers and removal of the whipped product from the cylindrical shell of the mixer flask.

2. Apparatus for whipping animal butter from multicomponent raw materials based

on a fermented dairy matrix and additives of plant and animal origin.

Consisting of permanent and interchangeable elements, wherein the permanent elements include spindles positioned within a drive bracket for rotating the interchangeable elements, sharing a common axis of rotation and carrying a mixer carrier frame, predominantly square in shape, with fixation and sealing units for the mixer flask shell and hemispherical covers arranged along its diagonals. The ends of the mixer flask shell include conical recesses into which conical projections of the hemispherical covers are inserted. The hemispherical covers contain conical openings at the top of the hemisphere into which fixing and sealing elements are inserted, at least one of which includes a ball valve connected, in the fixed position of the element, to the internal volume of the mixer flask.

3. Apparatus for whipping animal butter from multicomponent raw materials based on a low-fat fermented dairy matrix and modifying additives of plant and animal origin.

Including permanent and interchangeable elements kinetically connected through rotation mechanisms and mechanisms for generating reciprocating movement of the whipped masses of the specified multicomponent raw materials, wherein the installation axes of the permanent and interchangeable elements are positioned at an angle relative to each other, and the axis of rotation of the spindles included in the kinematic chain of the permanent elements is arranged horizontally.

4. Apparatus for whipping animal butter containing modifying additives of plant and animal origin from multicomponent raw materials based on a fermented dairy matrix with various fat-content parameters.

Consisting of an assembled and disassembled mixer flask having at least two fixation, sealing, and orientation centers relative to the mixer carrier frame, wherein one of these centers includes a device for the discharge of whipping waste products, and their axes are aligned with the axis of the specified flask. The flask is incorporated into an autonomous kinematic chain that generates reciprocating movement of the initial material inside the mixer flask along its axis, positioned at an angle relative to the rotation axis of a second autonomous kinematic chain connecting the drive bracket with at least two spindles, one of which is the driving spindle and the second is the driven support spindle. In addition, the rotation axes of both spindles coincide and are arranged horizontally.

5. Process of whipping animal butter containing various additives of plant and animal origin introduced into the initial product prior to the whipping process.

The process generally involves additives of plant and animal origin introduced into the initial product, in most cases in liquid form, before the butter-whipping process begins. The initial product consists of a liquid fermented dairy matrix which, after the introduction of additives, forms a multicomponent mixture in which the additives are incorporated into the base fermented dairy matrix.

The process includes sequential impact contact of the specified mixture with hemispherical surfaces that define the internal cylindrical volume of the assembled and disassembled flask. The impact interaction is performed in direct kinematic dependence on the rotational speed of the spindles included in the kinematic chain of the permanent elements of the apparatus implementing the process. The direction of reciprocating movement and kinetic acceleration continuously tends to change the direction of the movement vector and kinetic acceleration to the opposite direction relative to the instantaneous rotational phase of the assembled and disassembled flask.

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MODULES FOR ELECTRONIC LIGHTING SYSTEMS. (Integrative modules for electronic lighting systems in smart industrial facilities, including laser diodes, with an intensive cooling system based on diamond-copper composite materials)

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Abstract

As discussed in the article, innovative integrative solutions for electronic lighting systems based on laser diodes are considered, with a focus on efficient cooling, increased light output, and reduced energy consumption. Particular attention is given to the use of diamond-copper composite materials with a pseudo-porous structure, which provide intensive heat dissipation and stabilization of laser radiation parameters.

The article describes lighting device designs that utilize optical cables, phosphors, and laser radiation conversion systems to produce safe visible-spectrum light with high efficiency. Technological aspects of manufacturing composite elements, as well as the integration of thermoelectric cooling systems, are also examined.

Special emphasis is placed on the development of miniature and flat-emitter lighting devices intended for modern optoelectronic systems. The article highlights the importance of a comprehensive approach that combines traditional technologies, advanced composite materials, and computer modeling methods.

Such an approach makes it possible to create promising lighting devices ready for serial production and further technological modernization.

Keywords: *Integrative modules; Electronic systems; Laser diodes; Light output; Diamond spheres; Plastic material; Composite material; Pseudo-porous structure; Optical cable; Laser radiation; Flat emitter lamp*

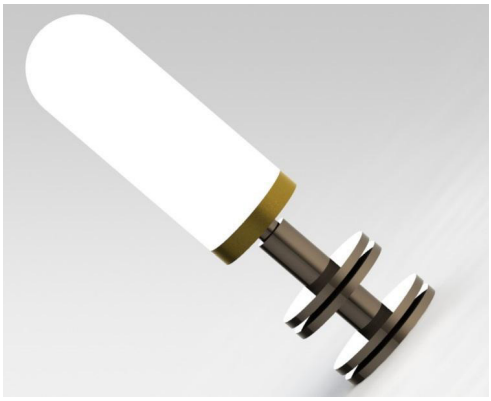
Introduction:

In order to eliminate energy losses and increase effective energy output, especially in various lighting systems, active research is being conducted into integrative technical solutions that make it possible to avoid the use of additional structural elements and additional energy consumption for cooling.

At the same time, technical solutions are being developed and refined that make it

possible, with the most concise and simple design, to increase the light output power of lighting devices while maintaining relatively low power and, accordingly, low energy consumption.

Figure 1. *The photo shows one of the innovative developments for converting laser radiation into light radiation within conventional and standard light spectra*



The author of this publication considers the most appropriate approach to be comprehensive integrative solutions within the framework of the proposals contained in the scientific and technological publications and books of Alisa Lahunina, a well-known innovation specialist in this field.

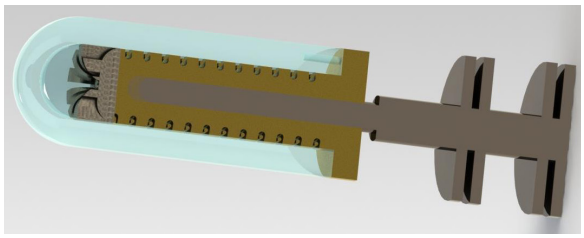
First of all, what distinguishes the proposals and developments of Alisa Lahunina from similar proposals by other authors is the extensive platform for experimental computer modeling, made possible by her broad and profound knowledge of the principal methods and techniques of systemic and combinatorial computer modeling within related innovative processes, including at the intersection of fundamental disciplines.

In analyzing all the innovative technologies proposed in her publications, Alisa Lahunina advances an exceptionally important thesis for solving the problem – the combinatorial structure of each solution, meaning the harmonious combination and mutual complementarity between traditional technologies and materials and innovative technologies and materials, primarily composite materials.

Moreover, among the proposals of Alisa Lahunina, the fundamentally important aspect is precisely the tendency toward integration and comprehensive adaptation of new materials and technological methods within the environment and conditions of existing and proven technologies and materials, prepared for the transformation of properties and capabilities at a new innovative level.

The following image shows an axial cross-section of such a device, which is more convenient for examination and analysis.

Figure 2. *The figure shows that the design of the innovative lamp combines the functions of several basic structural elements*



The lamp holder includes a vortex radiator, the shaft and disks of which are made from a diamond-copper composite, which is the most important component of the lamp cooling system.

Each component of this system is multifunctional. In addition to purely heat-conducting and heat-accumulating functions, the structure of these parts, made from numerous micro-globules of composite material, simultaneously performs the important function of dissipating heat flows, which is ensured by the pseudo-porous structure of the composite.

Let us consider the innovative structure of the diamond-copper composite in more detail (Source 1).

The original process of manufacturing the composite globules begins with the formation of diamond spheres made of synthetic diamond with a diameter of 5–7 microns (this size may vary depending on the profile and dimensions of the part, as well as its operating conditions).

After this, the spheres are coated with copper using specialized equipment and an original innovative technology (Source 2).

The thickness of the coating is selected in such a way that during the molding of the lamp component, there is sufficient plastic

material on the diamond spheres to enable the liquid-flow process of the metal and fill the cavities between the synthetic diamond spheres.

As a result, a pseudo-porous structure is obtained in which diamond spheres, representing the best heat-conducting material while being completely non-conductive electrically, are evenly distributed.

Such a structure makes it possible to instantly dissipate heat and distribute it evenly across the cross-sectional area of the radiator disks.

An optical cable is placed in the spiral grooves of the lamp housing, to which a beam of laser radiation is supplied from the laser module. The optical cable is wound into a spiral and placed in the housing grooves at a diameter that causes the cable to glow across the entire cylindrical surface, which is far more efficient than radiation emitted only from the cable end.

In order to separate the laser radiation from the output light radiation of the lamp, a phosphor layer designed for a specific radiation spectrum is applied to the optical cable.

As a result, the final radiation of the lamp is completely non-toxic and, due to the radiation area being thousands of times larger than that of the optical cable end, with a laser diode power of only 1–2 watts, the output equivalent of the lamp corresponds to 60–75 watts.

The presented models demonstrate that, based on the general principles of innovative design proposed by Alisa Lahunina, it is possible within the framework of traditional forms and constructions – for example, an ion-exchange filter – to achieve an almost ideal final result with unusual parameters and properties by using natural and completely safe materials:

- Complete absence of chemical reagents in the process.
- Use of natural ion-exchange conditions.
- Enormous potential for unique exchange capacity, including the purification of liquids contaminated with radioactive substances.

With such design tendencies, the requirements for design itself fundamentally change, making it possible to widely introduce computer modeling methods and techniques, as well as methods for achieving the ideal final result, into the development process.

Figure 3.

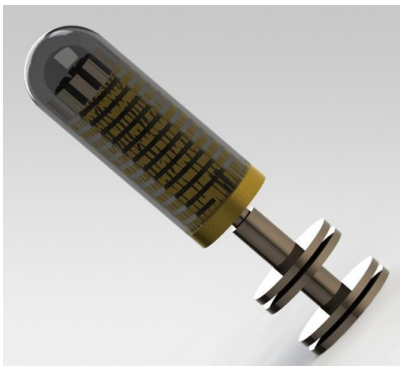


Figure 4.

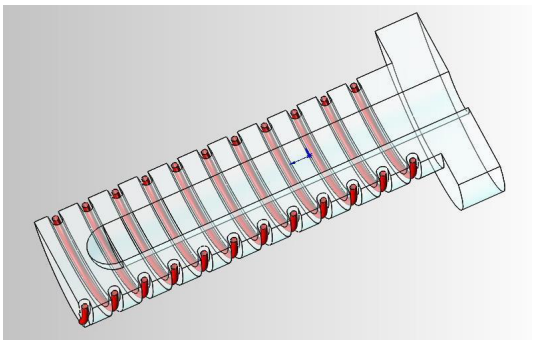
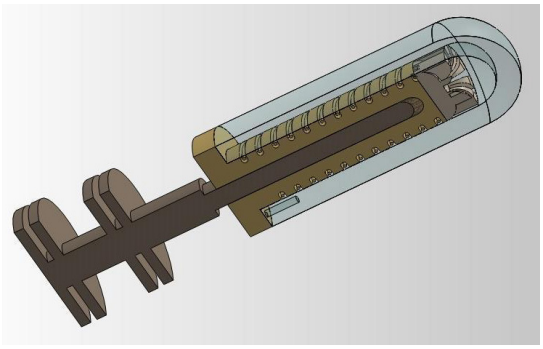


Figure 5.



The formation of radiation from the glow of an optical cable bent to a specific radius has many alternatives, such as the emitter shown in the following cross-sectional image, in which the cylindrical surface of the optical cable begins to emit light at a certain bending radius.

The proposed design contains many innovative elements and, most importantly, is fully ready for serial and mass production. In addition, the configuration of the lamp, together with its combination of technological principles and structural materials, makes it

possible to further integrate into the innovative product new technical solutions that may emerge during the continued development of laser technologies, composite material technologies, and new energy-efficient control and cooling systems.

Figure 6.

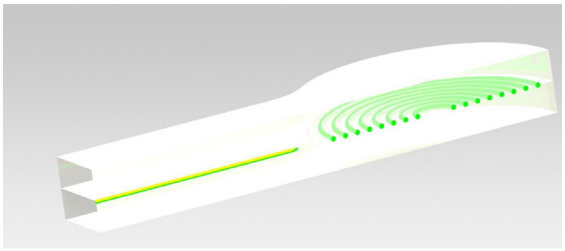


Figure 7. *Image shows a structural diagram of the lamp in a longitudinal cross-sectional view, where individual technical components are clearly visible, each of which carries a specific functional and technical purpose and performs particular technological and conceptual functions*

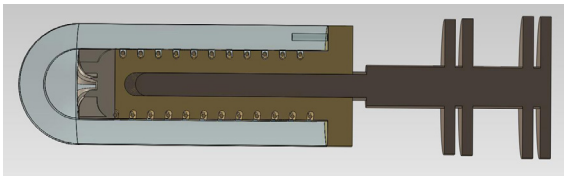
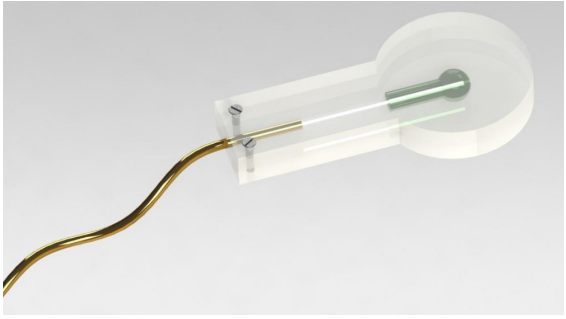


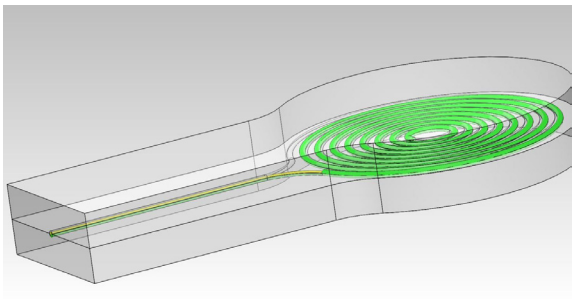
Figure 8.



The following image shows a mini-lamp in which a mixture of phosphors is applied to the end of the optical cable according to a specific geometry within a three-dimensional coordinate system, providing glow (radiation) in the white spectral range.

The diameter of the optical cable is only 120 microns, which makes it possible to create micro-miniature light sources for use in the most compact optoelectronic systems.

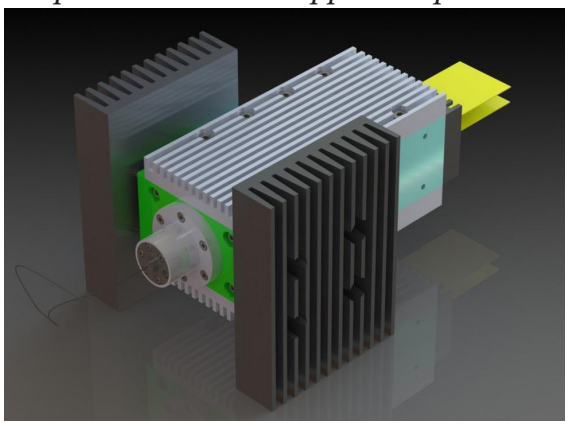
Figure 9. *Image shows a lamp with a flat emitter connected to only one optical cable*



In addition to overall efficiency, such a system makes it possible to achieve the required level of illumination over the required area with minimal cost and maximum simplicity.

The same system also makes it possible to apply virtually any combination or mixture of phosphors to the spiral (flat spiral) section at the end of the optical cable and obtain the required parameters of light radiation.

Figure 10. *A laser diode module built on the principles of active cooling through the dissipative effect in components made from a pseudo-porous diamond-copper composite*



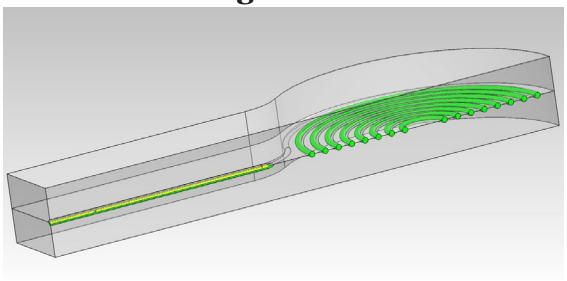
One of the innovative integrative features of the presented design is the use of thermoelectric coolers in combination with heat-conducting and heat-dissipating elements of the module housing structures.

The thermoelectric coolers are positioned between the external radiators and the module housing, while the heat-conducting structural elements transfer heat flows from the printed circuit board to the housing walls on which the thermoelectric coolers are mounted. In turn, the base planes of the radiators are pressed against these coolers, and, if necessary, other module components requiring

constant cooling may also be mounted on the radiators.

As practice has shown, reliable cooling makes it possible to maximize the stabilization of the output parameters of laser radiation, which in turn significantly expands the range of the module's output systems and, if necessary, makes it possible to distribute the laser radiation among several optical cables, each of which supplies one lighting device.

Figure 11.



The photo shows models of such devices.

Figure 12.

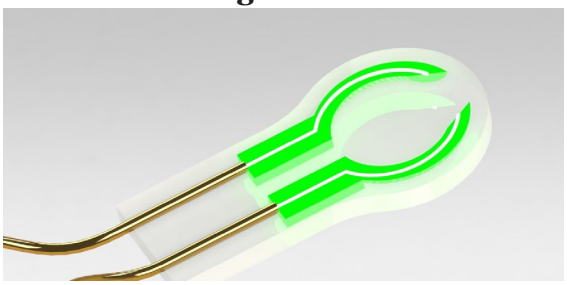
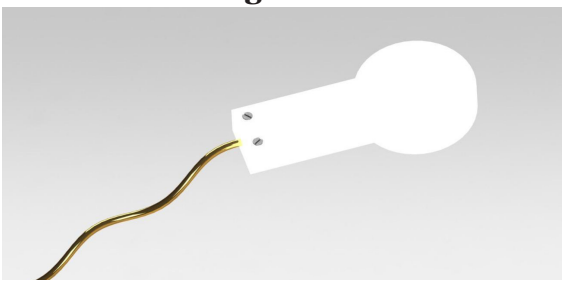


Figure 13.



The most important aspect remains the primary removal of heat directly from the laser diode.

The presented three-dimensional models show heat-conducting elements that simultaneously serve as the basic mounting components for securing the laser diode within the module housing.

As can be seen from the models, despite its simplicity and manufacturability, the supporting disk of the laser diode (highlighted in red in the models) completely protects the laser diode from overheating due to a number of factors, which, as mentioned above, significantly increases the stability of the module operation and reduces energy consumption for lighting.

The models also present a coding and decoding system that makes it possible to identify the optical cables connected to the module together with the lighting devices.

In addition to the primary operating functions, such a system provides the possibility of introducing and controlling various computer models for energy management and distribution.

These functions depend entirely on the purpose and operating conditions of the module, while the possibility of integrating the software component of the system precisely at the most critical point is of particular importance for the further development of the concept.

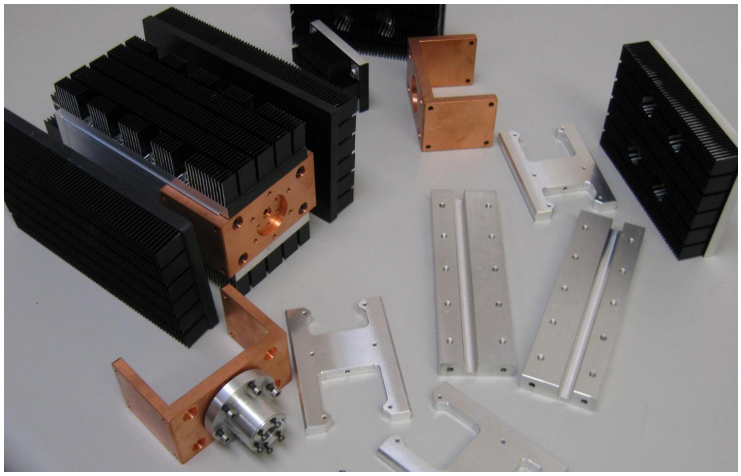
Furthermore, such a fundamental approach to the application of new composite materials in new applications with highly unusual properties and characteristics makes it possible to create new lighting devices and instruments with parameters required by modern technologies.

If attention is given to the fact that, in addition to the latest composite materials, nature also provides exceptionally valuable natural materials, then the application of the tendencies described in the publications of Alisa Lahunina also makes it possible to create a harmonious combination between long-known natural materials and repeatedly tested engineering and technological methods.

The conceptual solutions proposed by Alisa Lahunina make it possible, in the course of further development, for example of carbon-carbon composites in the form of fabric, to create solid components compressed from such fabrics that possess entirely unusual properties and open new innovative possibilities in lighting engineering and related processes.

As can be seen from the photo, all other components of the housing and cooling system of the laser module are made from standard profiles and materials and do not require any special materials or specialized technological equipment for manufacturing – everything is produced using standard cutting and measuring tools.

Figure 14. *Real structural elements of an innovative laser diode module with a cooling system and a laser diode holder made from a diamond-copper composite*



This can be regarded as an example of the integration and combination of innovative solutions for the efficient and safe conversion of laser diode radiation into safe and intensive phosphor radiation, with virtually complete heat dissipation and the absence of thermal and light losses.

All major output parameters of this integrated lighting system fully comply with current standards and safety regulations.

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ECOSYSTEM AND INFRASTRUCTURE OF A SMART IRRIGATION SYSTEM FOR DRIP IRRIGATION. (Linear equipment for drip irrigation with pre-saturation of water with oxygen before injection and with the possibility of using the same principle for cleaning and regeneration of linear pipelines of greenhouses and dairy farms)

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Abstract

The article examines the application of dynamic foam generators within integrated technologies for water treatment, regeneration, and recirculation, including their use in smart greenhouse systems and hydroponic complexes. Special attention is given to the influence of the scale factor on process efficiency and to the challenges of selecting optimal technological solutions among numerous existing methods. The study describes a new principle of foam generation based on the use of compressed air introduced into liquid through a device operating according to the Bernoulli principle, enabling precise control of bubble size and improving foam performance.

The paper highlights the simplicity, adaptability, and economic advantages of the proposed equipment, including linear systems for drip irrigation with pre-oxygenation of water and their application in pipeline cleaning and regeneration. It also presents modular and miniaturized water treatment systems suitable for small-scale operations, emphasizing cost-effectiveness and ease of maintenance. In conclusion, the proposed approach demonstrates high efficiency and versatility, contributing to improved performance of modern irrigation and water treatment systems.

Keywords: *Dynamic foam generators; dimensional factor of a foam generator; application of dynamic foam generators; integrated technologies; cleaning, regeneration, and recirculation of water; smart hydroponic system; control of heavy metal concentration; linear equipment for drip irrigation*

Introduction:

Application of dynamic foam generators in integrated technologies for water treatment, regeneration, and recirculation, including their use in smart greenhouse systems and smart hydroponic systems.

There are many different basic technologies for water treatment and regeneration of process water solutions, and a wide range of materials, including composite ones, is available on the market for the same purpose. However, when it becomes necessary to make a final decision on selecting a specific technology and material for a particular case, difficulties arise in comparative analysis.

The latest technological ideas in this and related fields encounter significant challenges during implementation due to the strong influence of the scale factor on the results of various operations in water preparation, purification, and regeneration for recirculation.

As is often the case in engineering, especially in innovative developments, gripping devices of specialized robotics have revealed properties and capabilities that ensure effective foam generation when compressed air from a vacuum gripping device, operating according to the Bernoulli principle, is introduced into a liquid (water).

During the first experiments, it was discovered that the prototype of the future foam generator, due to the air flow thickness being no more than a few microns, can regulate the diameter of air bubbles in the foam by adjusting the gap between the membrane and the housing.

This indicator and technical parameter proved to be extremely important, providing flexibility and a wide range of possibilities for foam generation processes based on a new principle.

In addition, the load-bearing capacity of the foam obtained in this way turned out to be significantly higher than that of conventional foam.

The ease and precision of regulating the diameter of air bubbles in the foam are demonstrated by the fact that the foam structure in the same liquid and in the same container can change when the gap between the membrane and the housing is adjusted.

This simplicity is ensured by the exceptionally simple design of the foam generator.

When forming irrigation systems, the cost factor is of the greatest importance, which in modern conditions of an innovation-driven economy and a market saturated with various types of equipment ultimately becomes decisive.

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This simplicity is ensured by the exceptionally simple design of the foam generator.

Linear equipment for drip irrigation with pre-saturation of water with oxygen before injection and with the possibility of applying the same principle for cleaning and regeneration of linear pipelines in greenhouses and dairy farms.

When forming irrigation systems, the cost factor is of greatest importance, which in the modern conditions of an innovation-driven economy and a market saturated with various types of equipment ultimately becomes decisive.

The first two photographs show models of a module for water treatment and regeneration for greenhouses.

The capacity of such a module is 2,000 liters per hour, and this value can be increased by adding two-section columns for ion-exchange purification of water or irrigation solutions.

Figure 1.

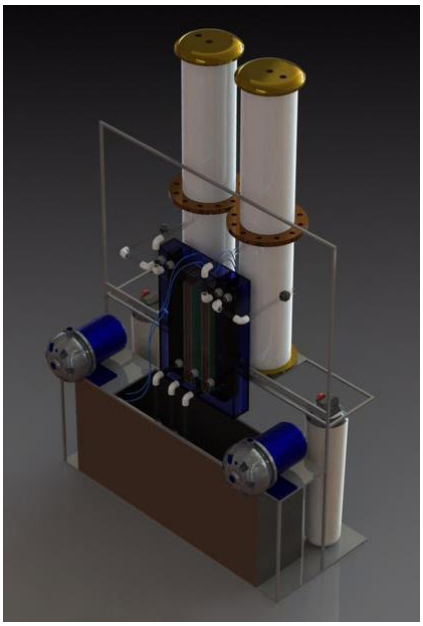
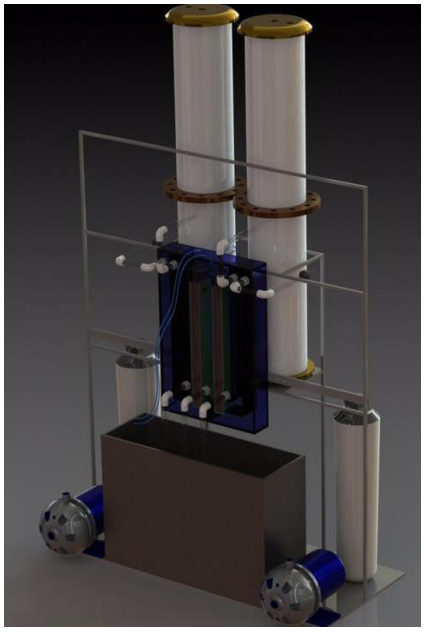


Figure 2.



As can be seen from the model, at least two additional columns can be used as a reserve, which can double the module's capacity. The same applies to increasing the number of electrochemical reactors by a factor of two.

The structure and cost, as well as the cost of operation and maintenance of specialized equipment for water treatment and purification, also play an important role in evaluating the cost factor.

Ultimately, these same factors affect the overall efficiency of greenhouse operations and the final cost of products.

Since the formation of conditions for capsule generation, as well as the mixing and dissolution of air and oxygen, occur directly in the drippers or nozzles, the module is freed from these functions, which makes all processes within the module more efficient and stable.

In order to максимально simplify the operating scheme of the module, a mini-module has been developed for very small greenhouses, the three-dimensional models of which are shown in the following two photographs.

As can be seen from these images, everything in these modules is максимально simplified, and the principle of communicating vessels is used for their operation, which made it possible to eliminate pumps.

Everything in these modules is extremely simple, and they can be serviced even by non-technical personnel; that is, such a module can be installed in a very small greenhouse and achieve maximum efficiency, essentially equivalent to that of a full-scale module.

Despite its simplicity, such a module can perform multifunctional tasks, and its presence in the irrigation equipment market can fundamentally change the situation and significantly increase the efficiency of relatively small greenhouse operations.

Importantly, the design of these modules allows the use of electrochemical reactors of various types and purposes, as well as inlet columns both with different types of fillers and without them.

All of the above can be implemented thanks to the method of electrochemical treatment in an upward flow of liquid, in this case water.

In addition to all the purely technological advantages, it is necessary to note the exceptional cost-efficiency of this type of equipment.

For small greenhouse operations, in order to maintain their competitiveness, the cost of such equipment should have minimal impact on the final cost of products.

In the case of irrigation technologies, the issue of minimizing water consumption and achieving water savings is also of primary im-

portance; however, both in engineering and in agricultural practices, environmental standards make this issue particularly critical.

Figure 3.

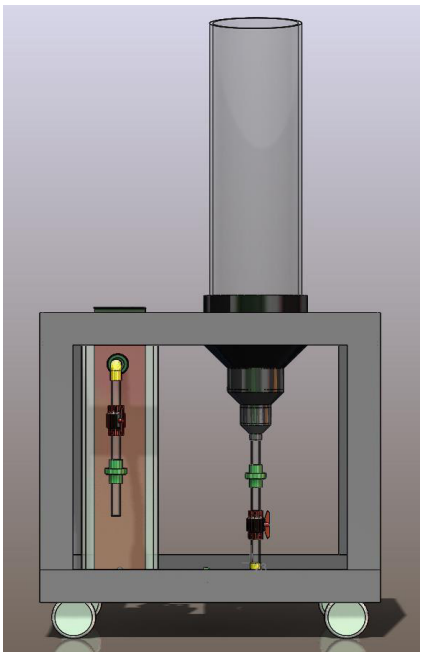


Figure 4.

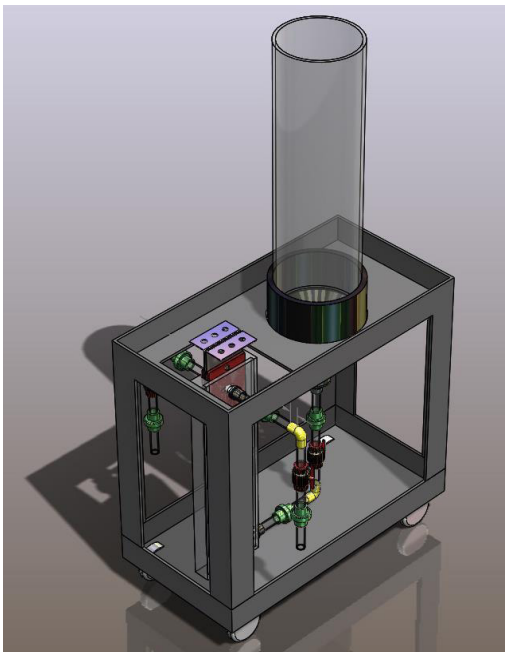
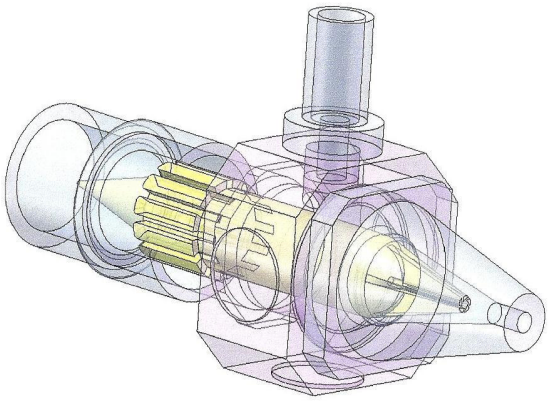


Table 5.



The requirement to comply with environmental standards, in addition to purely technical challenges, imposes additional responsibilities on developers of agrotechnological systems, both in terms of efficient use of water resources and in achieving the most effective application of water from the perspective of modern plant cultivation in specific greenhouses and hydroponic complexes.

One of the key factors in evaluating irrigation efficiency is the time factor, which determines the duration of contact between the root structure of cultivated plants and water.

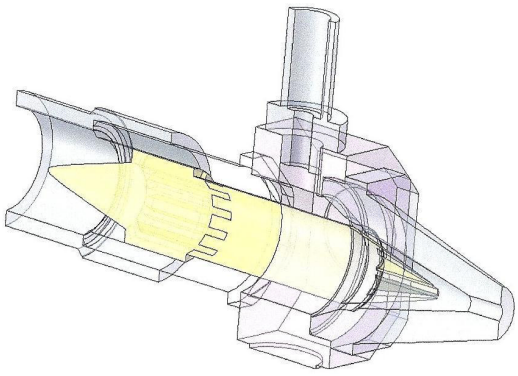
Considering that drip irrigation is currently recognized as the most effective method, the saturation of water droplets with air before they reach the soil is one of the factors determining success.

The presented three-dimensional models show variants and designs of drippers with integrated devices for mixing and saturating water with air bubbles.

When designing such drippers, several limiting factors were taken into account, in particular the requirement for efficient operation at low water and air pressure, as well as the requirement for uniformity of air bubbles within the water capsules.

Given the need for a large number of such drippers, their cost-effectiveness is a key factor in solving the problem.

Table 6.



To substantiate the high economic efficiency of the drippers, it is also necessary to note their exceptional structural simplicity combined with maximum functionality.

What is especially important is that the design of the drippers contains no moving parts, and the structural implementation of the components and the entire device allows for mass production using any production cycle, from a wide range of materials and manufacturing methods.

Extensive possibilities for optimization and modification of the product make it possible to produce several variations of these изделия in parallel on the same production equipment while maintaining the required quality level and with minimal costs for reconfiguration and adjustment of the manufacturing process.

Considering that the main consumers of this range of products will be relatively small enterprises and greenhouses with limited resources, such an approach to design and to defining technical characteristics makes it possible to achieve maximum commercial success while preserving existing production equipment.

All dripper components are easily unified and can be manufactured both by machining and by injection molding.

Figure 7.

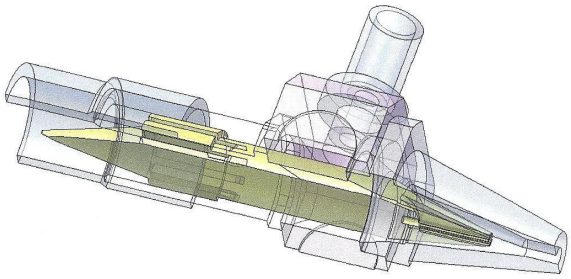
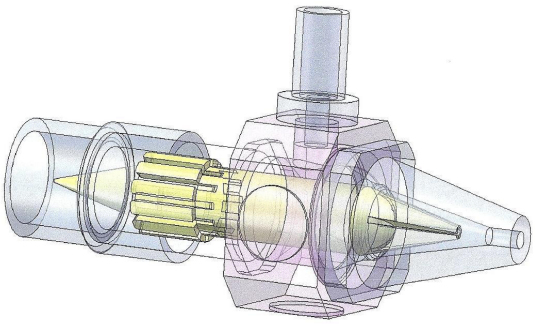
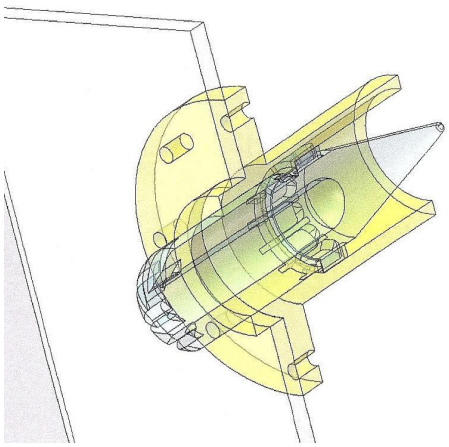


Figure 8.



The same devices can be used with a high degree of efficiency as nozzles and effective mixers for all types of liquids.

Table 9.



In addition to their use in the format of drippers with pre-injection treatment, these same designs can be applied with slight modification as active local mixers.

For this purpose, instead of an injector, a vortex generator is implemented on the central element, which injects the supplied liquid into the process vessel in the form of a vortex hydrodynamic stream.

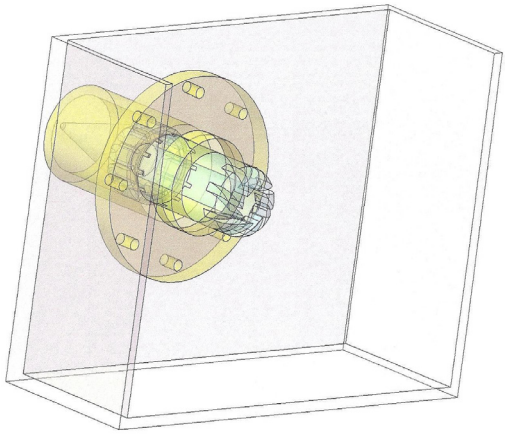
As a result, stagnant zones in the process vessel are eliminated, and the injection process is integrated with the process of hydrodynamic activation of the solution within the process vessel.

In application to the storage of hydroponic solutions in intermediate technological containers of small volume, where standard activators cannot be used, the use of drippers modified with vortex generators for hydrodynamic activation makes it possible to achieve the required level of storage quality for hydroponic solutions, with almost complete unification of technological equipment and a significant reduction in maintenance, adjustment, and operational costs.

The positive properties and capabilities of such equipment also include the ability to combine the process of introducing liquid into the process vessel with the involvement

of the introduced liquid in the process of hydrodynamic activation, with minimal costs.

Table 10.

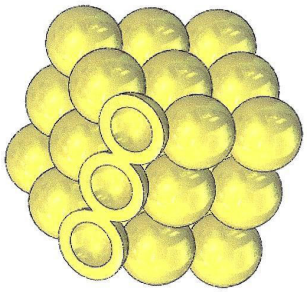


The use of these devices as activating elements in stagnant zones of process baths and vessels makes it possible not only to significantly improve the quality of process solutions, but also to ensure the real possibility of continuous regeneration of these solutions in order to reduce their consumption and lower storage costs for process solutions and liquids.

The dripper designs can also be independently used as both linear and local foam generators.

Analysis of the foam produced by such generators has shown a clearly defined capsule structure, in which numerous microcapsules are present, each containing a compressed air or gas bubble as the core, while the surrounding оболочка is formed by the base liquid of the solution, most often water.

Table 11.



Structural transformation in such foam makes it possible to obtain a so-called compressible liquid.

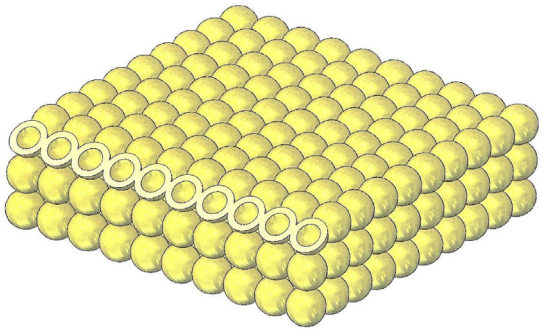
If, in an electrochemical reactor, a liquid with a high level of alkalinity is produced without the use of chemical reagents, then the foam from such a liquid becomes an ideal cleaning and disinfecting agent, especially for cleaning and disinfecting surfaces intended for bonding reinforcing or light-protective films.

In addition, further study of solar energy processes has revealed a significant shortage of silicon for the production of solar panels.

Increasingly, specialists are turning to the application of silicon films onto pre-treated glass surfaces.

Before application, in order to prevent various chemical reagents and heavy metal ions contained in water from reaching the glass surface, it is best to treat the surface using alkaline and acidic solutions that do not contain chemical reagents – that is, foam obtained from water with adjusted acidity or alkalinity.

Table 12.



Use of flexible membranes and thin films:

- instead of conventional structures, use flexible membranes and thin films;
- isolate the object from the external environment using flexible membranes and thin films.

This approach should be divided into micro- and macro-level components.

This method is also an important element, for example, in nanoscale technologies.

Consider, for example, the process of preparing a fuel emulsion. If an emulsion is formed, for instance, from diesel fuel and water, the only guarantee of the success of such a fuel emulsion is its structure, in which micro-droplets of water are surrounded by a thin film of diesel fuel.

After such an emulsion is injected into the combustion chamber, the water, which evaporates earlier than the diesel fuel, breaks the diesel оболочки into nanoscale particles during evaporation, which is far more effective for achieving an optimal combustion process than, for example, a sharp increase in injection pressure that would require strengthening the structural elements of the cylinder-piston group of the engine.

This same approach can form the basis for inventions in which, for example, an electronic board in areas intended for intensive heat exchange is coated with an ultra-thin film of synthetic diamond.

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ENHANCING THE EFFECTIVENESS OF COMMAND AND OPERATIONAL COORDINATION IN FIREFIGHTING AND RESCUE OPERATIONS IN HIGH-RISE APARTMENT BUILDINGS FROM THE FUNCTIONAL PERSPECTIVE OF THE FIRE AND RESCUE POLICE FORCE

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Abstract

This study focuses on analyzing the characteristics of high-rise apartment buildings that are directly related to firefighting and rescue operations. It clarifies the roles, functions, and responsibilities of the Fire and Rescue Police Force in command and operational coordination in accordance with current legal regulations, with particular emphasis on the Law on Fire and Rescue enacted in 2024. On this basis, the paper evaluates practical implementation and proposes feasible solutions aimed at enhancing the effectiveness of command and operational coordination in firefighting and rescue activities in high-rise apartment buildings, thereby meeting task requirements under the new operational context.

Keywords: *Firefighting and rescue; high-rise apartment buildings; firefighting command; Fire and Rescue Police Force...*

1. Introduction

The rapid process of urbanization in recent years has strongly stimulated the development of high-rise apartment buildings, particularly in major urban centers such as Hanoi. Alongside their significant economic and social benefits, this type of building also entails numerous potential risks related to fires, explosions, and complex incidents and accidents. Practical experience indicates that fires occurring in high-rise apartment buildings often result in extremely serious consequences, directly affecting human lives, property, and social order and safety. Typical examples include the Carina Plaza apartment fire, which occurred at 00:30 on March 23, 2018, at No. 1648 Vo Van Kiet Street, Ward 16, District 8, Ho Chi Minh City, Vietnam, resulting in 13 fatalities, 70 injuries, and economic losses estimated at VND 126 billion; as well as the mini-apartment fire at 11:30 on September 12, 2023, at Alley 29/70 Khuong Ha Street, Thanh Xuan District, Hanoi, which caused 56 deaths and 37 injuries.

In this context, command and operational coordination in firefighting and rescue

operations plays a particularly critical role and is decisive in determining the effectiveness of incident response. The Fire and Rescue Police Force serves as the core force directly responsible for performing these tasks in accordance with its legally prescribed functions and responsibilities.

2. The role of command and operational coordination in firefighting and rescue operations in high-rise apartment buildings

High-rise apartment buildings are characterized by complex architectural structures, high residential density, and diversified technical systems. When a fire occurs, it often generates a large volume of smoke and toxic gases that rapidly spread along the vertical axis, posing significant challenges to fire access and the organization of evacuation and rescue operations. Therefore, command and operational coordination must ensure unity, flexibility, timeliness, and accuracy in order to effectively mobilize and deploy forces and equipment, organize firefighting and rescue operations efficiently, and minimize human casualties and property losses to the greatest extent possible.

Command in firefighting and rescue operations is not merely the issuance of orders at the incident scene, but rather a comprehensive process involving situation assessment, anticipation of incident development, and the selection and continuous adjustment of tactical plans in accordance with the specific characteristics of each building and each operational phase. In the context of high-rise apartment buildings, the role of the incident commander is of paramount importance, as any error or inadequacy in on-site command and operational coordination may lead to extremely serious consequences.

3. Existing limitations and challenges in command and operational coordination of firefighting and rescue operations in high-rise apartment buildings

First, limitations in on-site command and operational organization

Practical experience indicates that, although the Fire and Rescue Police Force has made considerable efforts in organizing command and operational coordination for fires and incidents in high-rise apartment buildings, certain shortcomings remain evident in complex situations. The establishment of on-site command and staff units, as well as the assignment of responsibilities among functional sections, has at times lacked clarity and consistency. In emergency conditions involving multiple participating forces, command directives have occasionally been disrupted or insufficiently synchronized, thereby affecting overall operational effectiveness.

The primary causes of these shortcomings stem from the inherent complexity of high-rise structures, characterized by confined spaces, multiple floors, and various access routes, combined with the involvement of multiple agencies and forces. Without a well-defined and tightly organized command mechanism, such conditions are likely to result in overlapping or fragmented direction and control.

Second, difficulties in initial situation assessment and the development of tactical plans

In practical firefighting and rescue operations in high-rise apartment buildings, the collection of initial information to support command and operational decision-making remains challenging. Information regarding structural characteristics, technical systems, the location of the fire or incident, the number of trapped occupants, and the operational status of internal fire protection systems is often incomplete, inaccurate, or updated with delays.

Furthermore, some firefighting and rescue plans for high-rise apartment buildings were developed in advance but have not been promptly reviewed or adjusted to reflect changes in building functions, architectural modifications, or residential density. As a result, the application of these plans in real-world situations has been hesitant and has not achieved the desired level of effectiveness.

Third, limitations in personnel, equipment, and access conditions

Despite increased investment and attention, firefighting and rescue equipment for high-rise operations in certain localities remains insufficiently modern and synchronized when compared to practical operational requirements. Specialized equipment such as aerial ladder trucks, high-altitude rescue devices, and dedicated reconnaissance tools

is still lacking or does not adequately meet the height and scale demands of newly developed apartment buildings.

In addition, complex urban traffic conditions, limited access spaces, and the encroachment upon internal roads and parking areas within apartment complexes further hinder the deployment of forces and equipment, as well as the organization of firefighting and search-and-rescue formations in accordance with the incident commander's operational requirements.

Fourth, insufficient coordination among participating forces

In incidents and fires occurring in high-rise apartment buildings, in addition to the Fire and Rescue Police Force, various other actors are involved, including in-house firefighting units, local authorities, medical services, power utilities, and other relevant agencies. However, in practice, coordination mechanisms among these forces have not always been sufficiently well-integrated in certain situations. Information sharing, technical support, logistical coordination, and the maintenance of public order and security have at times been delayed or inadequately synchronized, thereby adversely affecting the overall effectiveness of command and operational coordination.

Fifth, persistent risks in ensuring the safety of firefighting and rescue personnel

Firefighting and rescue operations in high-rise apartment buildings inherently involve a high level of risk due to factors such as dense smoke, toxic gases, the potential for fire spread, localized structural collapse, confined spaces, and limited escape routes. Meanwhile, strict compliance with safety procedures and regulations in certain emergency situations remains challenging. In addition, personal protective equipment in some units is not yet fully adequate or synchronized, which negatively affects the ability of officers and firefighters to conduct operations safely and sustainably.

Sixth, the application of science, technology, and digital transformation in command and operational coordination remains at an early stage

At present, the development of comprehensive digital databases on high-rise apartment buildings to support command and operational coordination in firefighting and rescue activities has not been implemented in a synchronized and systematic manner. The utilization of data from automatic fire alarm systems, surveillance cameras, and building management systems remains limited and has not yet been effectively integrated into on-site command operations.

Furthermore, the practical application of advanced technologies-such as unmanned aerial vehicles (UAVs), drones, thermal imaging cameras, and digital platform-based command systems-in firefighting and rescue operations in high-rise apartment buildings is still relatively limited. These technologies are largely used on a pilot or experimental basis and have not yet fully realized their potential in supporting incident commanders in situation assessment and decision-making processes.

4. Proposed solutions to enhance the effectiveness of command and operational coordination in firefighting and rescue operations in high-rise apartment buildings

Based on the legally prescribed functions and responsibilities of the Fire and Rescue Police Force, and with the aim of enhancing the effectiveness of command and operational coordination in firefighting and rescue operations in high-rise apartment buildings, the following integrated solutions should be implemented in a systematic and coordinated manner.

First, improving the quality of unified on-site command and operational organization

It is necessary to further refine and improve the organizational mechanisms for command and operational coordination in firefighting and rescue operations in accordance with the principles of centralized and unified command, ensuring clear assignment of personnel, tasks, and responsibilities, as well as the smooth transmission of command directives from the command post to operational teams. In this regard, the authority and responsibilities of the on-site incident commander at each phase of incident response should be clearly defined in order to minimize overlap and fragmentation in command and operational control.

In addition, priority should be given to enhancing command capacity through

systematic training, professional development, and the organization of drills closely aligned with complex fire, accident, and incident scenarios commonly occurring in high-rise apartment buildings, such as basement fires, vertical fire spread, localized structural collapse, and situations involving large numbers of occupants trapped at elevated levels. Through training and exercises, the leadership competence, situational judgment, and ability to make rapid and accurate decisions of incident commanders can be progressively strengthened, thereby meeting the practical demands of firefighting and rescue operations.

Second, strengthening capacity for situation assessment and tactical planning

Efforts should be intensified to improve the collection, integration, and analysis of initial information from the moment a fire alarm or incident report is received. This includes data on building characteristics, the location of the fire, the scale of the incident, the estimated number of potentially trapped occupants, access conditions, available water sources, and other emerging hazards. Accurate, comprehensive, and timely situation assessment constitutes a critical foundation for incident commanders to select appropriate, effective, and safe tactical options.

At the same time, emphasis should be placed on the development, review, and regular updating of firefighting and rescue plans tailored to each specific high-rise apartment building, ensuring consistency with actual architectural features, functional use, and technical infrastructure. During operations, incident commanders must flexibly adjust tactical plans in response to the evolving dynamics of fires, accidents, and incidents, while assigning the highest priority to life-saving missions, minimizing property losses, and ensuring the safety of forces engaged in firefighting and rescue activities.

Third, strengthening investment in personnel and equipment tailored to the specific characteristics of high-rise apartment buildings

Continued attention should be given to investment in and procurement of modern and specialized firefighting and rescue equipment designed for high-rise buildings, including aerial ladder trucks, high-pressure fire engines, high-altitude rescue devices, specialized reconnaissance tools, and dedicated communication systems.

In parallel, measures should be implemented to address existing challenges in accessing incident scenes. This requires close coordination with local authorities and apartment building developers to ensure the availability of internal access roads and suitable deployment areas for firefighting and rescue vehicles, thereby effectively supporting command and operational coordination as well as the organization of tactical operations.

Fourth, enhancing the effectiveness of organization, mobilization, and coordination among forces and equipment

Coordination mechanisms between the Fire, and Rescue Police Force and in-house firefighting units, local authorities, medical services, power utilities, and other relevant agencies should be further refined throughout firefighting and rescue operations in high-rise apartment buildings. The focus should be placed on developing clear and specific coordination protocols that define the responsibilities of each participating force, along with strengthening inter-agency training and joint exercises. These measures aim to ensure timely and unified information exchange, maximize collective operational capacity, and enhance the effectiveness of command and operational coordination in handling complex fires, accidents, and emergency incidents in high-rise apartment buildings.

Fifth, reinforcing safety assurance throughout operational activities

Regular inspection and supervision of compliance with safety procedures, regulations, and requirements in both training and operational contexts should be maintained. Adequate provision of personal protective equipment for officers and firefighters must be ensured. At the same time, emphasis should be placed on training and strengthening safety-related skills and techniques in order to enhance operational proficiency, reduce risks, and minimize occupational accidents during firefighting and rescue operations.

Sixth, promoting the application of technology and digital transformation in command and operational coordination

Priority should be given to the development and completion of comprehensive

digital databases on high-rise apartment buildings, including information on structural characteristics, technical systems, access and evacuation routes, and water sources serving firefighting and rescue operations. At the same time, greater emphasis should be placed on strengthening connectivity and effectively exploiting data from automatic fire alarm systems, surveillance cameras, and building management systems in order to provide timely and accurate support for on-site command and operational coordination.

Concurrently, the application of advanced technological equipment and tools in firefighting and rescue operations should be intensified. Particular attention should be paid to the use of unmanned aerial vehicles (UAVs) for aerial reconnaissance missions, enabling the collection and real-time transmission of images and data related to fire development, smoke and toxic gas spread, the location of victims, and potential hazards such as structural collapse and fire propagation. On this basis, incident commanders are provided with a scientific foundation for situation assessment, tactical adjustment, and the timely, effective, and safe organization of firefighting and life-saving operations.

In addition, further research and gradual application of specialized UAVs and drones should be undertaken for tasks such as the deployment of firefighting agents, lighting support, evacuation guidance, and assistance in accessing and rescuing victims in elevated or hard-to-reach locations. These efforts should be integrated with the use of thermal imaging cameras and digital platform-based command and control systems, in conjunction with training and capacity-building for technologically proficient human resources, in order to meet the requirements of digital transformation in the operations of the Fire and Rescue Police Force in the current context.

5. Conclusion

Enhancing the effectiveness of command and operational coordination in firefighting and rescue operations in high-rise apartment buildings is an urgent requirement in the context of rapid urbanization and the increasing development of high-rise housing. As the core force in this field, the Fire and Rescue Police Force must continue to fully perform its assigned functions and responsibilities, while constantly innovating and improving the quality of command and operational coordination in order to meet the requirements of protecting human lives and property and ensuring public safety under the new operational context.

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BRAINSTORMING INCENTIVES FOR A STARTUP WORKING GROUP. (Professional distinctions and awards and their impact on the psychological climate in a startup working group during brainstorming sessions)

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Abstract:

The article examines the influence of professional awards and distinctions on the psychological climate within startup brainstorming groups, emphasizing their effects on creativity, motivation, and team cohesion. Particular attention is given to the role of recognition systems in strengthening employee engagement, fostering a culture of success, and supporting the development of innovative projects in the fields of smart technologies, artificial intelligence, and artificial neural networks.

The article also analyzes the relationship between brainstorming processes and brain activity, including the influence of psychological stress and external factors on the generation of innovative ideas. In addition, it discusses the stabilizing role of public scientific awards in startup environments and highlights the growing impact of artificial intelligence on human behavior and communication. The study concludes that a balanced system of professional recognition combined with effective brainstorming approaches can significantly enhance the development of innovative startup projects.

Keywords: *Startup; Startup team; Brainstorming; Professional awards; Psychological climate; Smart technologies; Artificial intelligence; Neural networks; Brain activity; Psychological stress; Startup concept; Innovation development; Technical specifications; Innovative product; Hardware systems; Software structures; System integration; Project management; Creative process; Idea generation*

Analysis of Brain Responses to Intensive and Active Participation in Systematic Brainstorming Aimed at Intensifying the Development Process of an Innovative Integrated and Modular Project in the Fields of Smart Technologies with Elements of Artificial Intelligence and Artificial Neural Networks.

Specialists continuously analyze brain responses to participation in brainstorming activities. Depending on the nature and specifics of the brainstorming process, par-

ticular brain regions have been identified that become activated according to the complexity and intensity of the psychological stress experienced during brainstorming, the characteristics of technical specifications, the required qualifications of brainstorming participants, as well as various distracting factors and even an individual's affinity for nature and its specific features.

At first glance, determining how the brain reacts to active participation in brainstorming appears to be a very difficult task. One cannot simply place a person in a scanner as soon as they begin participating in a brainstorming session.

However, in reality, the task is much simpler. When recalling real events, the brain activates the same patterns that were active during the actual formation of a project concept, at least with regard to a specific startup project task. Such precision is ensured by an experiment involving the systematic transformation of information and technical requirements and characteristics with the goal of creating a complete foundational framework for a project through the introduction of active elements of artificial intelligence and artificial neural networks into the management and control structure.

Participants involved in the relatively long initial stage of forming an innovative startup concept were simply asked to recall the state they experienced during the initial phase and during the successive intensification of subsequent brainstorming steps, while continuously correcting and refining the objectives for analyzing the brainstorming structure in close alignment with the technological and technical structures of the startup project.

Strictly speaking, the results obtained at intermediate stages of brainstorming correlate specifically with the sequential analysis of the achieved effect rather than with actual indicators of technical characteristics, although brainstorming processes these states in a similar manner.

The effectiveness of brainstorming manifests itself in many forms: from the emergence of an idea or interconnected ideas for a new invention to the prediction of technical characteristic parameters, the use of which creates a clear picture of the algorithm and structure of the invention formula in general, and specifically of independent claims. Their combination, under conditions of complete uncertainty, creates a clear relationship between independent claims and their corresponding dependent claims.

Such approaches to processing and analyzing the condition of structural and schematic solutions for a new innovative product make it possible to create an integrative invention that considers all nuances of technical characteristics by incorporating into a hierarchy all interconnected parameters of both hardware and system components together with applied software structures and methods for their effective use.

Thus, brainstorming makes inventions with formal patent structures realistic, including: an apparatus (device), a system, a program, and an associated method.

The formation of so-called smart technologies during brainstorming opens new opportunities in which all parameters and characteristics can be analyzed step by step, with complete control of parameter changes at each stage of the brainstorming process.

For example, colleagues asked an experiment participant: "Imagine that you are seeing your project for the first time. What do you feel?" Have you achieved the ideal final result in implementing the idea?

Specialists found that the highest brain activity occurs specifically during the experience of the presence or absence of the effect of achieving an ideal final result.

"In this case, activation was observed deep within the brainstorming system along with the emergence of new and sufficiently effective brainstorming topics."

Brainstorming participants recorded sharply increasing brain activity associated with environments whose design could be categorized as reflecting an affinity for nature.

(In other words, according to experimental results, a "love for birch trees" or another landscape significant to a person is not a myth.)

Researchers found that an affinity for nature activated the brain's organizational system, while areas associated with social behavior and unrelated to the project itself were not activated.

The situation with pets appears somewhat different. Affection for pets may trigger additional brain activity during brainstorming associated with social interaction.

The analysis of the physiological aspects of brainstorming may seem like a cold and unnecessary experiment, but specialists and leading startup employees hope that their research and experiments may be used for better treatment of depression or for solving problems in organizing brainstorming processes through the use of 40 methods and techniques for achieving the ideal final result in accordance with the Theory of Inventive Problem Solving (TRIZ).

Professional awards and distinctions have a significant, although ambiguous, influence on the psychological climate within a brainstorming group. They are capable of both stimulating creativity and strengthening cohesion, while also potentially causing a decline in motivation if applied improperly.

The impact of rewards can be divided into positive and risky effects:

Positive Impact (Increasing Effectiveness):

- Enhanced engagement and motivation: Teams receiving frequent recognition are more engaged and productive. Employees whose efforts are rewarded generate twice as many ideas;
- Formation of a culture of success: Public recognition creates an atmosphere in which the contribution of each participant is valued, thereby increasing trust in leadership;
- Group cohesion: Rewards (especially team-based rewards) contribute to a "shared celebration" of success, bringing participants closer together and creating a safe environment for exchanging ideas;
- Stimulation of creative self-efficacy: Positive verbal rewards strengthen employees' belief in their creative abilities, which is critical for effective brainstorming.

Risks and Negative Impact (Reduction of Creativity):

- Overjustification Effect: If creative activity (brainstorming) begins to be perceived solely as a means of obtaining external rewards (money, certificates, awards), intrinsic motivation and creativity may decline;
- Focus on speed rather than quality: Rewards based on the number of ideas may lead to the generation of a large number of weak and stereotypical ideas instead of high-quality ones;
- Risk of conflicts: Individual rewards within a creative group may provoke envy, feelings of unfairness, and undermine the atmosphere of mutual support.

Recommendations for Maintaining a Positive Psychological Climate:

1. Encourage the process, not only the result: Reward bold attempts and initiative, not only successfully implemented ideas.

2. Use non-monetary incentives: Professional recognition, public praise, or providing a choice of rewards (project selection, an additional day off) work better than money alone, without creating a sense of external "control."

3. Team rewards: Recognize the achievements of the entire group in order to strengthen collaboration.

4. Fairness and transparency: The criteria for receiving rewards should be clear and achievable for all participants.

Conclusion: Rewards are effective if they support the intrinsic drive for creativity rather than replace it. In a brainstorming group, the key factor is maintaining a balance between recognition of achievements and preserving a sense of freedom and equality.

The award concept of the International United Academy of Sciences (IUAS 2.0) is based on the principles of recognizing scientific achievements, supporting innovation, and developing the scientific community in a digital format. IUAS positions itself as the world's first online academy.

Main Provisions of the Award Concept:

- Independent evaluation: The award system is aimed at recognizing works that have received high evaluations within the scientific community;
- Digital format (IUAS 2.0): Since IUAS 2.0 operates online, application procedures and award presentations are

likely optimized for a digital environment;
- Competency development: The award system (including projects such as IUAS.TESTS) is intended to help researchers build professional portfolios, identify strengths, and confirm qualifications.
- Reward structure: Traditionally, the concept includes the assignment of statuses (membership), as well as the presentation of diplomas, certificates, or medals confirming the status of a participant or winner.

Features:

1. Accessibility: Interaction with the academy takes place through a browser or smartphone, making participation and receiving awards accessible to specialists from anywhere in the world.

2. Professional development: Awards and assessments are intended to promote the development of scientific activity.

Social Privileges:

Over the past year, many events have taken place, and membership in IUAS has become almost a mandatory condition for scientific work for researchers in Russia. The social status of IUAS members has become even more important and increasingly necessary.

Partner services with discounts or complimentary benefits.

In IUAS 2.0, we abandoned our own ecosystem of scientific services, as it required additional costs. However, IUAS members still enjoy a wide range of privileges and bonuses. This has been achieved through cooperation with partners and the creation of beneficial partnership arrangements.

Additional opportunities and activities for IUAS members.

IUAS includes many interactive modules available to holders of IUAS membership status.

IUAS has now become open.

IUAS is not a rigid or overly formal scientific organization. It is an open community of researchers where there is a place for everyone. In version 2.0, additional opportunities have been introduced even for those who have not yet obtained membership status.

The concept of awards of the International Academy of Sciences (IAS) (and its associated structures such as the International Academy of Sciences and Arts, RAE, and others) is aimed at recognizing outstanding achievements of scientists, educators, and public figures.

Main principles and objectives of the awards:

- **Recognition of scientific achievements:** Awards are presented for outstanding scientific works, discoveries, inventions, as well as for series of scientific studies on a common topic;
- **International scope:** Citizens of any country with significant achievements may be eligible for awards;
- **Development of professional education:** Awards often recognize contributions to the development of higher education and professional training systems;
- **Encouragement of active participation:** Orders and medals (for example, the CONCORD Order) are awarded to academy members for successfully fulfilling plans and actively participating in the organization's activities;
- **Social and practical significance:** Works with substantial scientific, practical, and social importance are recognized.

Types of awards:

1. Honorary titles and gold medals: For example, "Laureate of the Sevastopol Academy of Sciences Award."

2. Orders: For example, the CONCORD Order and the Order of Catherine the Great "For Service to Science and Education."

3. Prizes: Awarded for scientific results obtained through collaborative research activities.

The award campaign is aimed at supporting a high standard of scientific research and recognizing the achievements of researchers within the scientific community.

The concept of establishing the stabilizing role of public awards, considered within the context of public academies and civil society institutions, is aimed at creating a system of independent recognition of achievements that complements state

incentive mechanisms and contributes to social cohesion.

Key aspects of the stabilizing role of public awards:

- **Recognition of significant achievements:** Public awards, unlike state awards, often promptly recognize achievements in highly specialized or emerging areas of science, culture, and social activity that are not yet covered by official award systems.
- **Social motivation:** Awards from public academies encourage active civic engagement, constructive activity, and the pursuit of professional excellence, thereby reducing social tension.
- **Ideological function:** By encouraging activities aimed at the development of science, culture, and humanitarian cooperation, public awards help shape positive values that contribute to social stability.
- **Connection between civil society and the state:** Public academies serve as a bridge between the state and professional communities, helping to objectively assess individual contributions.

Elements of the concept:

1. Objectivity and expert evaluation: The granting of awards is based on a multi-stage expert review process within the professional community, ensuring recognition of genuine contributions.

2. Independence: Public awards are free from political influence, which increases trust in the incentive system.

3. International dimension: Such projects are often aimed at combining cultural potential and expanding cooperation between countries.

Such a system of incentives not only recognizes achievements but also shapes social etiquette by indicating the place of award recipients within the system of social relations.

Awarding startup participants with distinctions from public academies of sciences (RAS, RAEN, and specialized academies) is a powerful tool for **psychological stabilization** and non-material motivation, especially under conditions of high uncertainty, limited resources, and stress. Such an approach helps strengthen the team's confidence in the chosen direction, increase loyalty, and reduce staff turnover.

Below is an analysis of the mechanisms through which awards from public academies contribute to the stabilization of startup teams.

1. Strengthening psychological ownership and belief in the project.

- **Legitimization of efforts:** Awards from public academies function as "social proof" of the scientific or technological significance of a project. This confirms that sweat equity – substantial efforts invested despite low financial compensation – has not been in vain;
- **Stress reduction:** Recognition by the expert community reduces anxiety among founders and employees associated with the risk of failure, thereby increasing their resilience.

2. Strengthening identity and a "culture of winners".

- **Status and pride:** Receiving an academic award (a medal or honorary title) in a formal setting (for example, at national academies or specialized institutions) creates a strong emotional experience that cannot be replicated through financial bonuses;
- **Shared purpose:** Recognition highlights outstanding participants while simultaneously uniting the entire team around a common value – the pursuit of innovation and scientific novelty.

3. Team stabilization mechanisms (Retention).

- **Non-material motivation:** In situations where a startup cannot offer high market-level salaries, academic recognition becomes an effective tool for retaining key talent by satisfying the need for social status.

4. Impact on external stakeholders (investors and partners).

- **Increased trust:** Awards from academies of sciences, including public

academies, serve as a signal to investors that the technology has undergone a certain level of validation.
- **Professional reputation:** The presence of "academically recognized" experts within the team enhances the startup's prestige in the eyes of potential clients and partners.

How to implement an award system to achieve stability

1. Link awards to values: Reward not only the achievement of KPIs but also the demonstration of values such as initiative, creativity, and mutual support (e.g., CRISPY Awards).

2. Make the ceremony public: Conduct award ceremonies during team meetings and share information through social media and newsletters.

3. Combine recognition with growth opportunities: Offer award recipients access to mentorship programs or new challenging opportunities (scientific conferences, publications).

Conclusion

Awarding distinctions from public academies contributes to startup stability by shifting the team's focus from short-term difficulties to a long-term mission, while fostering a sense of pride and professional belonging.

At the same time, the continuous expansion of artificial intelligence applications requires particularly close attention, and this topic has already been covered in the media.

Italian medical specialists reportedly diagnosed, for the first time, a case described as a clinical dependence on a "chatbot." Publications referring to the government service SERD (Center for Disease Control and Prevention Service) reported this case.

The case concerns a young woman approximately 20 years old living in Venice. She is currently undergoing therapy at the Addiction Treatment Service of the municipal healthcare administration.

Representatives of the service noted that they primarily deal with "substance addictions," including drug and alcohol dependency. In principle, behavioral compulsive disorders are also known, including addictions related to gambling, shopping, computer games, smartphones, social networks, and even work.

However, such conditions rarely progress to clinical stages. For example, among four thousand patients in the Venice service, only six adolescents were unable to overcome compulsive dependence on computer games and excessive smartphone use.

Dr. Laura Suardi, head of the Addiction Treatment Service, explained to journalists that such dependence may develop in psychologically vulnerable individuals through gradual interaction with artificial intelligence. If designed for this purpose, AI adapts to the user, provides responses perceived as pleasant, and communication with the machine may become more attractive than communication with peers, especially since much social interaction today also occurs through messaging. Dialogues with a "chatbot" may develop into a close "friendship" and subsequently into dependency.

Individuals experiencing a psychological vacuum – primarily young people – communicate with mobile devices as though they were full conversational partners or even wise advisors, sharing personal problems and seeking advice on highly sensitive matters.

In cases of such attachment, attempts by parents or others to separate individuals from this dependency often provoke irritation and resistance. Therefore, physicians predict an increase in similar cases as young people become more engaged with "chatbots," a process that is currently only beginning.

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INTERNATIONAL TRENDS IN IMPROVING THE OPERATIONAL EFFICIENCY OF RENEWABLE ENERGY ASSETS: TECHNICAL AND ECONOMIC APPROACHES

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Abstract

The article examines trends in improving the operational efficiency of renewable energy assets, taking into account the interrelation between technical and economic approaches to their operation. It is shown that current management practice for solar and wind facilities is increasingly based on digital monitoring, predictive maintenance, generation forecasting, energy storage integration, and operating cost optimization. The approaches applied in the United States, Kazakhstan, and a number of countries with a developed renewable energy sector are analyzed. It is established that the most promising model is integrated asset management, in which technical reliability, system flexibility, and economic performance are treated as interrelated elements of a unified operational strategy.

Keywords: *renewable energy, operational efficiency, asset management, predictive maintenance, digital monitoring, operating costs*

Introduction

Renewable energy development is increasingly shaped not only by the expansion of solar and wind capacity, but also by growing attention to the operational efficiency of assets already in service. At this stage, the competitiveness of renewable energy facilities depends not only on electricity output, but also on stable generation, high technical availability, controlled operating costs, and predictable financial results. The relevance of this study lies in the fact that improving operational efficiency is becoming a key factor in the resilience of energy companies under growing infrastructure complexity and long-term asset value management requirements.

The purpose of this study is to analyze international trends in improving the operational efficiency of renewable energy assets through a comparison of technical and economic approaches used in current management practice. Particular attention is paid to the relationship between technical operating parameters and the economic outcomes of asset management.

Methods

The methodological framework of the study was based on the analysis, synthesis,

comparison, and generalization of academic literature, industry analytical materials, and international operational practices related to solar and wind power facilities. To identify stable approaches to improving efficiency, the study used a comparative analysis of engineering solutions in monitoring, maintenance, diagnostics, and digital asset management, as well as economic instruments associated with operating cost optimization, improved equipment availability, and higher financial returns. In addition, a systems approach was applied, allowing operational efficiency to be examined as the result of the interaction between technical reliability parameters, organizational management mechanisms, and economic criteria for evaluating operational performance.

Operational efficiency of renewable energy facilities: content and key indicators

Under current conditions, the operational efficiency of renewable energy facilities should be regarded as an independent asset management category rather than merely a derivative of installed capacity or electricity output. This perspective is justified by the scale of growth in the sector itself: according to IRENA, global renewable energy capacity additions reached 692 GW in 2025, bringing total installed renewable capacity to 5,149 GW, while renewables accounted for 85.6% of total power capacity additions worldwide (International Renewable Energy Agency, 2026).

From a theoretical perspective, the operational efficiency of a renewable energy asset is an integral characteristic reflecting its ability to provide the maximum possible and stable useful output at an acceptable level of operating costs, technical losses, and downtime. To present the content of operational efficiency more clearly, it is advisable to systematize the main indicators used for its assessment (table 1).

Table 1. *Main indicators for assessing the operational efficiency of renewable energy facilities*

Indicator	Description	Significance for assessing operational efficiency
Technical availability of equipment	Reflects the share of time during which the equipment remains in working condition and is able to perform its functions.	Demonstrates operational reliability and the ability of the facility to ensure continuous electricity generation.
Capacity factor	Shows the extent to which the installed capacity of the facility is utilized over a given period.	Makes it possible to assess actual operating performance and compare potential and real electricity output.
Duration and frequency of downtime	Shows the length and recurrence of equipment shutdowns caused by failures, maintenance, or external constraints.	Allows assessment of operating stability and the effect of disruptions on total electricity generation.
Technical losses	Includes electricity losses associated with conversion, transmission, equipment limitations, and deviations from normal operating conditions.	Characterizes the extent to which actual results differ from the technically achievable level.
Compliance with operating standards	Reflects the degree to which technical requirements, design conditions, and operating regulations are observed.	Allows assessment of operational correctness and the risk of reduced reliability and equipment lifetime.
Operating costs	Includes expenses related to maintenance, repair, diagnostics, monitoring, and associated operational processes.	Shows the economic efficiency of operation and the cost level required to maintain asset performance.

Indicator	Description	Significance for assessing operational efficiency
Recovery time	Characterizes the time required to eliminate a failure and return the equipment to normal operation.	Reflects the quality of operational management and affects the volume of lost electricity generation.

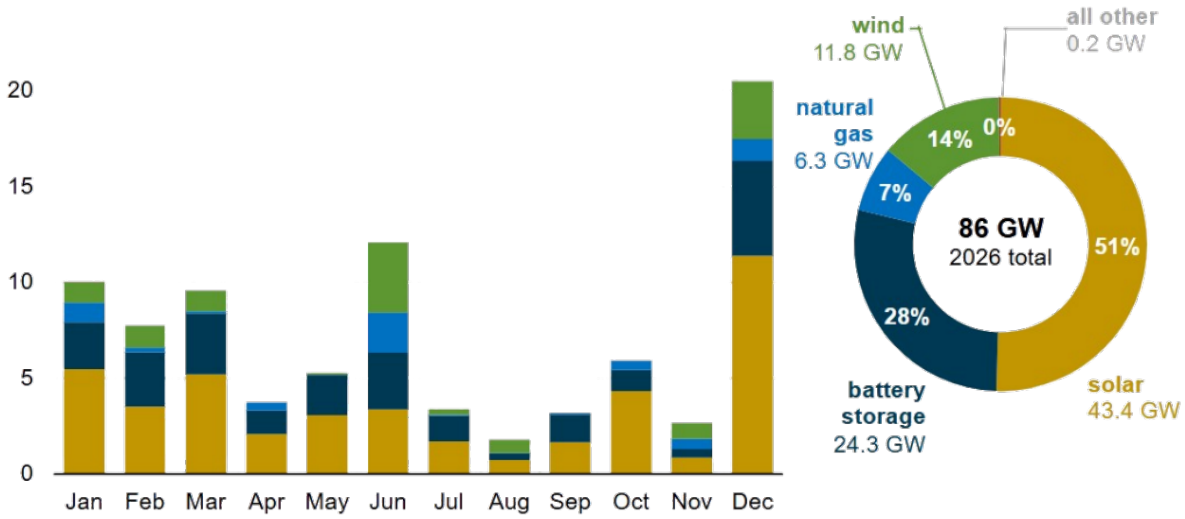
The quantitative relevance of these indicators is evident from the wide variation in operating results even among technologically mature renewable energy facilities. According to NREL, the expected capacity factor for utility-scale solar PV ranges from 21.4% to 34.0%, while U. S. Energy Information Administration (EIA) data for the United States in 2024 show actual monthly values of 13.4–31.6% for utility-scale solar and 25.2–43.7% for wind power. At the same time, Fraunhofer ISE reports that the typical performance ratio of modern photovoltaic systems in 2025 is about 80–90%, while NREL uses an availability benchmark of about 95% for wind assets. These data indicate that operational efficiency should be understood as a multidimensional characteristic shaped by resource conditions, technical reliability, maintenance quality, and operating management rather than by installed capacity alone.

International application of technical solutions to improve the operational efficiency of renewable energy assets

Efforts to improve the operational efficiency of renewable energy facilities are becoming less reliant on routine maintenance and more dependent on continuous operational data. This shift is reflected in models combining SCADA monitoring, forecasting, predictive analytics, digital twins, storage, and flexible dispatch control. The International Energy Agency (IEA) links this process to successive phases of VRE integration, while the World Bank/ESMAP emphasizes forecasting for lower balancing costs and curtailment, and IEA PVPS highlights digital twins for photovoltaic performance analysis, predictive maintenance, and lifecycle decision support.

At present, the most advanced technical model can be observed in the **United States**, where improvements in operational efficiency are increasingly based on the combination of data-driven O&M and the accelerated integration of energy storage systems. Based on the data from the EIA, it is clear that solar energy production combined with storage and utility-scale storage were anticipated to account for 81% of all new capacity additions in 2025. The latter was estimated to increase by 18.2 GW. In 2026, the operators of U.S. power plants have planned to expand their capacity by 86 GW (fig. 1).

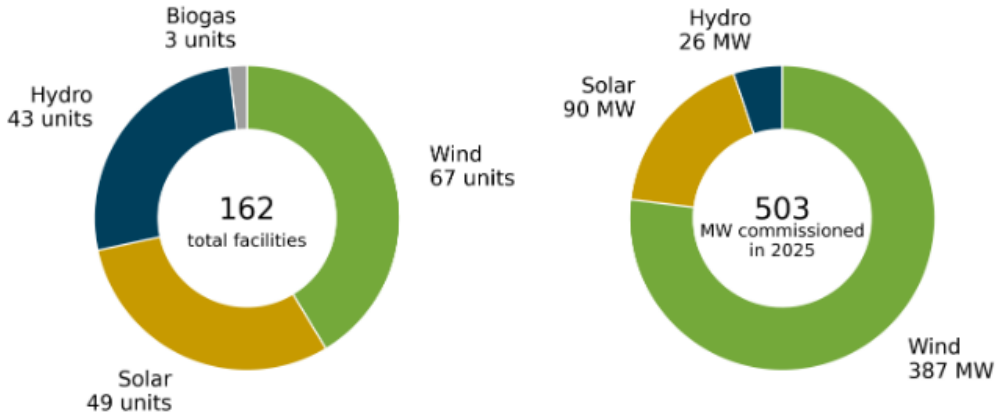
Figure 1. *Structure of planned new utility-scale generating capacity additions in the United States in 2026, GW (EIA, 2026)*



For operational practice, this means a shift from managing an individual power plant to managing a hybrid energy asset, where efficiency is determined not only by electricity output, but also by the ability to smooth the generation profile and support grid stability. U.S. practice is also characterized by a high level of maturity in the analysis of operational data: reliability studies of utility-scale solar use the PVROM database, which contains operations, maintenance, and production records for more than 50,000 O&M tickets from 837 sites across the United States.

In **Kazakhstan**, the adoption of modern technical solutions in renewable energy is developing under conditions of rapid transformation of the entire power system. According to expert estimates, whereas 10–12 years ago the total installed capacity of renewable energy facilities in the country was about 200–250 MW, by early 2026 it had approached 3.5 GW. At the same time, the share of renewables in annual electricity generation reached 7% by 2025 and continues to grow (fig. 2).

Figure 2. *Structure of operating renewable energy facilities in Kazakhstan and structure of newly commissioned renewable energy capacities in 2025 (Ministry of Energy of the Republic of Kazakhstan, 2025)*



Under these conditions, the technical priority is shifting from simply expanding installed capacity to improving the flexibility, stability, and controllability of the power system. Greater importance is now attached to flexible generation, energy storage, digital monitoring, and accurate forecasting, since system reliability depends not only on the scale of new capacity additions, but also on the quality of grid integration. Overall, Kazakhstan is moving toward a more advanced model of renewable asset operation, in which operational efficiency depends on grid integration, generation predictability, balancing resources, and the maturity of energy infrastructure management. This direction is consistent with the national target of carbon neutrality by 2060 and was further supported in 2025 by memorandums signed with the European Investment Bank and the EBRD to finance renewable energy, grid modernization, and large hydropower projects.

European practice shows that as the share of renewables rises, technical solutions become increasingly specialized and focused on system flexibility. **Denmark** remains one of the clearest examples: according to the latest fully reported annual data, wind and solar generation reached 24,329 GWh in 2024 and covered 63% of national electricity demand, confirming the country's position as a leader in variable renewable energy integration. In **Germany**, however, we see a distinct approach, where, in 2025, renewables supplied 55.9% of gross public power production, wind still led as the source of power production, while photovoltaic production grew by 21%, surpassing lignite power production for the first time. All of these examples demonstrate that, when renewable energy production is mature enough, efficiency does not rely exclusively on growth in power production capacity.

An example of Asian practice is **China**, which demonstrates a large-scale model of digitally and market-managed renewable

energy operation with a pronounced dominance of solar generation. According to official data, by the end of 2025 the country's installed solar capacity had reached 1.2 billion kW, while installed wind capacity amounted to 640 million kW. This indicates that the specific feature of the Chinese model lies primarily in the large-scale expansion of photovoltaic systems, whose integration requires grid adaptation, digital control, and market-based coordination of operating modes.

From a comparative perspective, Denmark can be seen as a benchmark of system flexibility, Germany as a benchmark of technological modernization of the existing fleet, and China as a benchmark of scalable digital operation and a high level of installed capacity utilization.

International organizations and cooperative platforms play an important role in shaping these approaches by transforming fragmented national practices into reproducible technical solutions. The IEA provides a framework for assessing renewable integration maturity, the World Bank/ESMAP develops guidance on forecasting and grid integration, IEA PVPS systematizes reliability and digital twin solutions for photovoltaics, and IEA Wind Task 43 advances data standards and digital O&M models for wind energy. As a result, the international trend is shifting from operating renewable facilities in isolation to managing them as part of a digitally coordinated energy ecosystem spanning equipment, plants, the grid, and the overall asset portfolio.

Economic mechanisms of operational efficiency in renewable energy assets

In international practice, the operational efficiency of renewable energy assets is increasingly assessed from the perspective of economic performance. At a mature stage of sector development, competitiveness depends not only on new capacity additions, but also on stable output, controlled operating costs, acceptable electricity cost, and predictable financial results. Under these conditions, renewable asset management includes not only project capital parameters, but also O&M optimization, contractual mechanisms, energy storage, and portfolio management (table 2).

Table 2. *Main economic instruments for improving the operational efficiency of renewable energy assets (Emblemsvåg, 2025; Abreu et al., 2025)*

Instrument	Economic content	Significance for improving operational efficiency
LCOE-based management	Assessment of the cost of electricity over the asset life cycle, taking into account both capital and operating expenditures.	Makes it possible to relate technical decisions to the long-term economic efficiency of the project.
O&M cost management	Control and optimization of expenditures on maintenance, repair, diagnostics, and monitoring.	Contributes to reducing specific operating costs while maintaining equipment reliability.
Performance-based contracts	Contractual arrangements in which the operator's compensation depends on achieved operational results.	Increases the operator's responsibility for availability, output, response time, and loss reduction.
Integration of energy storage	Use of storage systems to smooth the generation profile and increase the economic value of delivered electricity.	Reduces losses associated with curtailment and improves revenue stability.
Portfolio asset management	Operational decision-making based on the combined profitability and risk profile of a group of assets.	Makes it possible to coordinate maintenance, modernization, and resource allocation at the portfolio level.

The economic significance of these instruments is reflected not only in the cost of electricity, but also in the structure of operating expenditures and in the ability to maintain asset performance over time. In this context, the efficiency of renewable energy asset operation depends on how effectively technical reliability is translated into controllable costs, stable output, and lower revenue losses. Therefore, economic assessment at the operational stage is primarily associated with O&M cost management, the design of contractual incentives, the use of energy storage, and coordination at the portfolio level.

For example, in the United States, the U. S. Department of Energy estimates utility-scale PV O&M at about $19/kW DC per year for a 100 MW DC plant, while NREL reports a possible range of $0–$40/kW DC depending on project configuration and market conditions. For fixed-bottom offshore wind, total OpEx is estimated at $135/kW per year. At the same time, according to IRENA, the total installed cost of utility-scale BESS declined by 93% between 2010 and 2024, from $2,571 to $192/kWh. This indicates that economically efficient renewable energy operation depends not on simple cost reduction, but on cost optimization combined with reliability, flexibility, and effective asset management.

Thus, the economic performance of renewable energy assets should be assessed not only through electricity cost, but also through operating expenditure structure, contractual flexibility, and revenue resilience under changing system conditions (Lin & Zhu, 2025). Economically efficient operation therefore depends on the coordinated use of cost management, storage integration, and portfolio-level decision-making, forming a more integrated asset management model in which technical and economic parameters are treated as interdependent elements of operational efficiency.

Current trends in the integration of technical and economic mechanisms in renewable energy asset management

The current stage of renewable energy development is characterized by a transition from the separate use of engineering and financial instruments to their integration into a unified asset management system. Whereas technical operation was previously viewed mainly as a task of maintaining equipment functionality and economic efficiency as the result of investment and tariff parameters, these dimensions are now increasingly functioning as an interconnected management model (Eleiwi & Habeeb, 2025).

In practice, this means that improving the operational efficiency of renewable energy assets is increasingly based on a **data-driven management** architecture in which technical data are used directly for economic optimization. Digital twins, advanced SCADA monitoring, predictive analytics, IoT components, and decision-support tools are applied not only for equipment diagnostics, but also for selecting the most rational maintenance scenario, planning repairs, and reducing the risk of underproduction.

Artificial intelligence occupies a special place in this model because it already produces measurable effects in forecasting and maintenance of renewable energy assets. A 2025 systematic review in Energy Strategy Review showed that generative adversarial network models can reduce RMSE in solar forecasting by about 15–20% (Khouili, 2025). In photovoltaic maintenance, a 2025 review reported that CatBoost and Random Forest models achieved accuracy above 99% in multiclass fault diagnosis and PV performance prediction tasks (Vichare & Gaikwad, 2025). Together with digital twins, these results reflect a shift from simple digitalization to intelligent management aimed at better maintenance decisions and lower revenue losses.

One of the clearest international trends is the integration of **flexibility into operational efficiency management.** As the share of renewables grows, output and availability alone are no longer sufficient, since curtailment, grid integration quality, temporal shifting of generation, and participation in balancing processes become increasingly important. The IEA notes rising curtailment in major markets, and reports that curtailed renewable generation in the European Union exceeded 10 TWh in 2024. This reflects a shift from measuring how much energy an asset produces to assessing how controllable, economically valuable, and system-integrated that generation is.

Another important trend is the **increasing scale of renewable energy facilities and the growing complexity of renewable asset portfolios**, under which operation can no longer be viewed as a set of isolated technical tasks and instead becomes a full-fledged management function. As projects move toward capacities measured in hundreds of megawatts and operators manage multiple heterogeneous assets simultaneously, the role of operational analytics, failure forecasting, coordinated maintenance decisions, and systematic workforce management becomes more significant (Joaqui-Barandica et al., 2025). Under these conditions, companies that invest early in a mature operating model achieve more stable output, greater predictability of financial performance, and a higher level of resilience to technical and organizational risks.

The economic integration of technical solutions is especially visible in the link between digitalization and storage economics. Falling storage costs and the growing role of batteries make storage not only a reliability tool, but also a means of improving generation revenues. According to IRENA, the total installed cost of utility-scale battery storage fell to $192/kWh in 2024, while the IEA reports continued battery price declines and about 63 GW of new utility-scale storage added in the power sector. At the same time, IRENA notes that 91% of new utility-scale renewable projects commissioned in 2024 generated electricity more cheaply than the cheapest new fossil-fuel alternative. As a result, asset management increasingly evaluates forecasting, diagnostics, storage integration, and dispatch through their impact on LCOE, O&M, curtailment losses, and cashflow stability.

Thus, current international trends point to a new renewable energy asset management model in which operational efficiency results from the integration of digital maturity, technical reliability, system flexibility, and economic controllability. This approach combines forecasting, equipment assessment, contract design, storage investment, and portfolio management within a single decision-making logic and appears to be the most promising for ensuring stable and profitable operation across the asset life cycle.

Conclusion

In current international practice, improving the operational efficiency of renewable energy facilities goes beyond the local refinement of individual operating procedures and increasingly takes the form of a complex management task. The efficiency of renewable energy assets is determined not only by the technical condition of equipment and the volume of generation, but also by the quality of integration of technical, digital, and economic mechanisms into a unified decision-making system. This approach makes it possible to view operation as a strategic function in which reliability, flexibility, controllability, and economic performance are shaped in interaction rather than in isolation.

On this basis, it can be assumed that the further development of renewable energy asset management models will be associated with the deepening of data-driven approaches and the wider use of intelligent analytics, digital twins, energy storage, and portfolio-based coordination methods. A particularly promising model is one in which technical decisions are assessed not only from the standpoint of engineering feasibility, but also in terms of their impact on financial resilience, power system adaptability, and the long-term value of the asset. It is precisely this management logic that creates the foundation for more mature, resilient, and economically grounded operation of renewable energy facilities throughout their entire life cycle.

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VORTEX GENERATOR; GASEOUS MEDIUMS VORTEX MIXING DEVICE. (Aerodynamic and Hydro-Dynamic Effective Technology For Vortex Tube Formation In Multi – Gaseous Medium's; Effective Multistage Cooling and Water Removing from Compressed Gaseous Stream's)

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Abstract

This article examines the design, operational principles, and industrial applications of an innovative vortex generator system intended for high-efficiency localized mixing, cooling, turbulence generation, and dynamic gas–air homogenization in industrial and energy-related processes. Particular attention is devoted to the constructive and functional advantages of the vortex generator, including its focused turbulent impact, modular architecture, controllable operational parameters, ease of installation and maintenance, resistance to corrosive and extreme-temperature environments, and capability for integration into existing technological systems with minimal modification. The article further analyzes the application of ring vortex generators for dynamic mixing of natural gas with compressed air, highlighting the formation of controlled vortex channels that enhance diffusion penetration, turbulence intensity, pressure vector stabilization, and kinetic energy accumulation within the mixed gas stream. It is demonstrated that such vortex-induced structural transformations of gaseous media contribute to improved homogeneity of combustible mixtures, enhanced combustion preparation, and increased process efficiency. The article concludes that vortex generator technology constitutes a versatile and commercially valuable engineering solution with broad applicability across modern industrial, thermal, chemical, and energy infrastructure systems requiring advanced fluid dynamic control, precision mixing, and optimized thermodynamic performance.

Keywords: *Vortex Generator, Gas Medium; Vortex Tube, Water Extraction from Compressed Gas Flow, Aerodynamic and Hydrodynamic Technology, Vortex Tube Formation, Series of Vortex Generators, Vortex Generator Functions*

Introduction:

Vortex Generator is the solution to many industrial problems and therefore has a large variety of applications. The device produces rushing fluid that emerges at a high velocity and possesses a high kinetic energy. This creates a highly turbulent and powerful action in the medium where the device is submerged. The Vortex Generator functions aerodynamically or hydro-dynamically, depending whether a compressed gas or a pressurized liquid is utilized as the active fluid.

The modular and mobile construction of the device allows it to be totally flexible and customizable to any relevant industrial application. It consists of a series of Vortex Generators that are arranged specifically, depending on the size and shape of the object being acted on. The shape and size of the Vortex Generators are also variable to fit the shape and size of the operative surface. The tubing on which the Vortex Generators are mounted can be rigid or flexible, and can have many configurations, which makes the device applicable in tight spaces such as pipes and narrow tubes.

Fast-propelled fluids have many industrial applications in cooling, cleaning, rinsing and mixing processes. When used for rinsing or cleaning, the device can be used on a local area or manipulated over a large area, as the application requires. Since it is light and maneuverable, it can be manipulated manually or automatically to bring it to the local operative surface or specific object. As an alternative, when the operative surface is extensive, a larger assembly consisting of many Vortex Generators can be assembled to operate simultaneously over the broad surface of the object.

The active power is greatest at the heads of the device; being applied locally at locations needed most. As a result, much less active fluid is utilized, reducing energy and time consumption. Another advantage of the device is the cooling. When combined with original Equipment, the Vortex Generator can be used as a more effective mixing and cooling system.

When used as a mixing apparatus, the device's action behaves as a highly efficient agent.

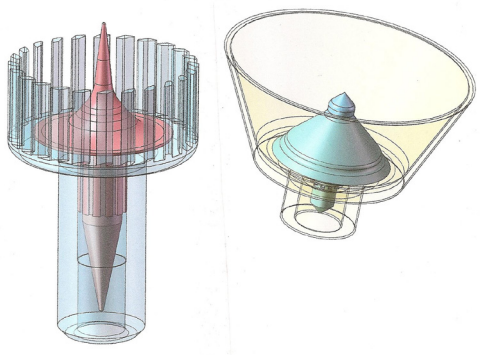
Taking into account its flexibility, maneuverability, and applicability, it becomes evident that Vortex Generator can serve as an extremely useful tool in today's diverse industrial market.

Table 1.

a) b) c)

Table 2.

a) b)



I. Advantages of Vortex Generator

Efficient performance

- The turbulent power of the Vortex Generator is not scattered over the entire medium, rather its full thrust is exerted locally (for cooling, like example) where it is needed most. As a result, much less active fluid is utilized, and less energy and time are consumed.

Complete control

- Since the active power of the Vortex Generator is focused, one can control how much and where to apply it. It can be applied more intensively on densely affected zones or evenly over the entire operative surface. The Vortex Generator also comes with a flow control valve that can be regulated manually or automatically. For example, in an automated system, the Vortex Generator can be mounted onto a robotic immersion arm and can be activated via a valve only while the object is submerged.

Modular design allows for easy customization

- The Vortex Generator System is comprised of multiple Vortex Generating Generators mounted onto tubing. Both the Vortex Generator and the tubing can be arranged in an unlimited number of configurations, each according to the size and shape of the operative surface. The Vortex Generator can thus be used in hard to reach places or tight spaces such as pipes and narrow tubes. The shape and size of the Vortex Generator are also variable to suit the physical parameters of the application. In addition, if process requirements change, the existing configuration can be adjusted accordingly to accommodate those changes.

Easy assembly and installation

- All of the tubing as well as the Vortex Generator's heads are assembled via threaded joints that simply screw into each other. The Vortex Generator's Assembly is provided with a flexible hose that is equipped with a standard hose fitting for easy connection to a source of compressed air.

Interchangeable parts

- All of the components are interchangeable and can be easily replaced even by non-technical operators, without the need for special tools or equipment. This gives the client an option to minimize down time by keeping a stock of replacement parts and servicing the Vortex Generator's System by himself.

Corrosion and extreme temperature resistant

- All of the components including the tubing and the Vortex Generator's are made of durable non-corrosive materials. These materials are resistant to reactive chemicals and temperature extremes, enabling to operate with virtually any active fluid and in any application. This translates into longer-lasting, more reliable performance.

Can be integrated into existing processes

- Vortex Generator's System can be connected into any functioning system with only minor modifications. No redesign or reconfiguration of the existing treatment process or its components is necessary. In many instances, the Vortex Generator can be used in addition to the existing system to supplement and enhance it.

Side benefits at use of a technique of vortex mixing natural gas with compressed air which arise at application of the device for mixing natural gas with air in the ring vortex generators located along one axis, conterminous with a direction of movement of a stream of natural gas;

The constructive device of vortex generators, allows to form a vortex pipe in which around of a stream of natural gas on a spiral the stream of compressed air which limits volume in which stream of natural gas and in which occurs diffusion penetration of compressed air into a stream of natural gas rotates moves;

Thus the vector of linear pressure of a mix in a direction of movement aside chambers of combustion accumulates kinetic energy of the incorporated streams of compressed air

both natural gas and kinetic energy of the vortex channel;

Such combination of energy and the form of the combined streams allows to mix dynamically an organic part of a mix with an oxidizer, keeping a high level of turbulence and uniformity of distribution of volumes of a stream in which the oxidizing agent and the combustible agent moves;

Process of mixing goes in parallel with physical transformations to gas streams which lead to structural changes in character of these streams, passing with reception of phase transformations of a condition of water;

Preliminary tests of a pre-production model of the device for mixing natural gas with compressed air, have shown correctness of these assumptions

So at submission in the device for mixing natural gas with the compressed air, compressed air under pressure in 3 atmospheres it was possible to receive a homogeneous stream of a mix with precisely designated vortex cylinder with pressure, a vector which is directed aside, conterminous with a direction of movement of a stream of a mix to the chamber of combustion and the level of the pressure equal to pressure in a stream of compressed air a minus pressure in a stream of natural gas, that is, – 3–1.5 = 1.5 atmospheres;

Thus streams of the compressed air having pressure above than a stream of natural gas, move on a tangential trajectory, compress a stream of natural gas and get into the center of this stream, keeping thus vortex character of movement;

Preliminary tests have shown a high level of controllability of process at the control and change only one parameter of mixing, – pressure in a stream of compressed air;

Process of mixing with use of vortex ring generators, has in parallel with diffusion mixing dynamic effect still a number of physical effects which are based on constructive advantages of system of ring vortex generators;

There is a speech about effects of the adiabatic expansions and movements of streams of the compressed gas in a vortex pipe which render an essential influence on temperature of gas streams;

Thus by results of preliminary tests it is possible to define presence of following advantages of vortex dynamic mixing of natural gas and compressed air:

– High uniformity of mixing; the level of uniformity between components of a mix on all volume of a mix makes more than 95% from all volume of a mix both in movement, and in static position;

– 100% an opportunity of the full control of proportions of mixing and concentration of components in a mix to within 1.5 milligram of natural gas on one liter of air;

– 100% an opportunity of change and adjustment of concentration and proportions of mixing;

– Low need for energy on process of mixing, due to use of some physical effects;

– 100% an opportunity of the control and regulation of temperature of a mix at all stages of mixing, including and a stage of formation of the vortex channel;

– An opportunity at mixing at the same expenses of energy to reduce temperature of a mix to necessary limits;

– An opportunity at controllable decrease in temperature in streams of components of a mix and in a stream of a mix after mixing to take from gases the water containing in them both simultaneously in regular intervals and homogeneously to distribute this water in the form of bubbles in the size of diameter no more than 10 micrometers on all volume of a mix in dynamic movement;

– 100% an opportunity to supervise and adjust pressure in a stream of a mix and speed of movement of a mix due to the control and changes only one parameter, namely pressure in streams of compressed air and natural gas.

Owing to the specified general parameters, there is a new level of operational advantages:

– A low general level of volume of all exhaust gases; an expected level of decrease more than 25% from volume of all exhaust gases arising at burning, – the reason sharp reduction of quantity of air of combustion directed to the chamber and not had time to take part during burning;

– A low level of toxic substances in exhaust gases, at a level of decrease on 75–95%, due to presence of particles of water in streams gas components of a mix, due to uniformity of a gas mix, due to a high level

of turbulence and dynamic volumetric three-dimensional mobility of a mix including during burning;

– Decrease in a level of the charge of a gas mix on burning, due to sharp reduction of expenses of time for hashing of natural gas with air and reception of a stable gas mix in which is available certain on its volume certain, controllable quantity of air homogeneously distributed on its volume;

– Decrease in the charge of natural gas on creation of a homogeneous gas mix and burning with reception of equivalent quantities of energy not less than on 25–45%, under condition of creation of a mix of a rattling mix not having proportions;

Considering explosion hazard of process, the active control of all elements of process has essential value;

The offered technology and its constructive realization, allow to conduct the control and management of process over a mode of real time with speed of reaction to any changes in parameters of process within the limits of 1 millisecond;

Additional opportunities which are available for system of dynamic vortex mixing streams of two gas environments

The design of the device for vortex mixing has high composition flexibility;

The same vortex generator can have the direction of tangential channels conterminous with a direction of a hour hand or directed counter-clockwise; it defines a direction of a vortex spiral and can serve as the tool for formation of various levels of turbulence in a stream of gases at mixing and after mixing;

At presence in the device for vortex mixing the several consistently located vortex generators, probably to change a direction of tangential channels at two adjacent vortex generators and to receive at the same expenses of energy increase in a level of turbulence of a mix in two and more times;

In the same way it is possible to adjust time in which current there is a process of mixing and formation of a vortex stream of a gas mix;

One of the important reserves of increase of efficiency of process of mixing is the opportunity of adjustment of pressure of gas environments in a wide range from 2 atmospheres up to 20 atmospheres;

Separate maintenance of each of vortex generators the compressed air and absolutely independent work of each of vortex generators, enable even within the limits of the same devices for dynamic vortex mixing gas environments to establish a various operating mode for each of vortex generators;

As owing to formation on an output from tangential channels of a local zone of adiabatic expansions it is possible to receive decrease in temperature of the gas leaving each channels, increasing or reducing pressure of air it is possible to receive various temperature;

At submission on the vortex generator of air under pressure in 20 atmospheres it is possible to receive negative temperature on an output from the channel and to take water from air in the form of microscopic crystals of an ice which presence at burning improves quality of burning and in addition reduces concentration of toxic substances in products of burning on size of concentration of water in a gas mix;

So, if water borrows in a mix of 10% from weight of a mix it is considered to be, that the level of concentration of oxides of nitrogen and carbon decreases also on 10%;

If in the device for dynamic vortex mixing there are some vortex generators changing pressure of air which moves on each generator it is possible to receive water only in that place which is necessary, keeping thus a consumption level of energy and a level of efficiency of the device for dynamic vortex mixing;

The characteristics of the device for dynamic vortex mixing gas environments and components includes the basic base parameters and additional parameters which are received in addition to the cores due to basic and design features of vortex generators and the device for the dynamic vortex mixing gas environments using vortex generators as the basic technological tool;

The basic attributes of a characteristics:

– Controllable dynamic vortex homogeneous mixing two or more gas environments;

– Controllable and adjustable maintenance of any proportions between mixed gases;

– Controllable and adjustable input of each gas by criteria of the charge, pressure, a level of turbulence, a level of temperature, a level of linear speed of a stream;

– Formation of a vortex pipe from a mix of gases;

– Formation of two basic criteria and base physical effects for decrease in temperature in a stream of gases on all length of a vortex pipe or on local sites of a vortex pipe;

– Controllable and if necessary changeable direction of a spiral in a vortex pipe on its all extent;

– Controllable and adjustable change of a level of turbulence of a stream of gases in a vortex pipe during and after mixing;

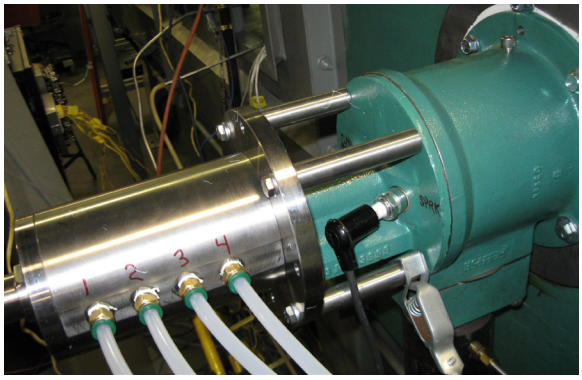
– Controllable and adjustable condensation of water in a stream of gases at mixing and after mixing;

– Controllable and adjustable value of linear speed of movement of a stream of gases in a vortex pipe;

– Controllable and adjustable value of pressure in a stream of gases in a vortex pipe and on an output from it;

– Controllable and adjustable change of a direction of a spiral in a vortex pipe without change of a design of the device for dynamic vortex mixing gas environments.

Table 3.



All the specified basic attributes of a characteristics are new and are directed on increase of efficiency of the device for dynamic vortex mixing gas environments

Advantages of technology to dynamic vortex mixing gas environments

Efficiency of technology and the device for dynamic vortex mixing gas environments

The technology of dynamic vortex mixing of gas environments which is based on application of consistently located vortex generators, owing to use simultaneously several dynamic physical effects, has low consumption of energy and has side benefits in the form of two steps of cooling of gases at mixing and at least double increase in a level of turbulence;

All it is carried out due to one energy source, – the compressor which compressed air or any other gas submits, on vortex generators of the device

The full control over a mode of real time above all working parameters of the device for dynamic vortex mixing gas environments

The control over work of the device for dynamic vortex mixing gas environments is carried out by means of the control of the charge and pressure over streams of gas components of a mix;

Such kind of the control does not demand what or special devices and by means of standard reliable decisions pressure can automatic remote be adjusted;

Modular design of the device for dynamic vortex mixing gas environments

The device for dynamic vortex mixing gas environments has a modular design as in one device all vortex generators have the identical sizes and functions both their quantity and combinations can change easily at the customer's request

Convenient change of the basic target characteristics of the device for dynamic vortex mixing gas environments proceeding from conditions of the consumer

Owing to that in the device the unified details and standard components are applied only, performance of changes in performance data of the device does not cause what or difficulties.

Convenient assembly and connection of the device for dynamic vortex mixing gas environments

Owing to a high level of unification and corresponding design of details of the device for dynamic vortex mixing gas environments, assembly of the device at the consumer, connection of the device to the process equipment

at the consumer are extremely simplified and do not demand non-standard decisions.

High level of interchangeability of details and components of the device for dynamic vortex mixing gas environments

As a rule in the device for dynamic vortex mixing gas environments 4 types of original details, all which design features are applied, the executive sizes and which principles of assembly are unified and correspond to requirements of operating standards.

The prevention of influence of corrosion and high working temperature; an opportunity of use of composite constructional materials

The design of details and components of the device for dynamic vortex mixing gas environments allows to make them of wide scale of constructional materials including composite materials steady against influence of corrosion and heats.

As in the device there are no mobile parts that and there is no harmful influence of corrosion and a heat on working capacity of the device.

Integration into any industrial technological process;

The device can be integrated into any technological process owing to that its running cycle and a high level of efficiency do not depend on external processes, and can be supervised and be adjusted on the minimal number of parameters in a mode of real time and with use of standard devices and adaptations.

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SCHEME OF MODULE ARRANGEMENT IN THE WATER TREATMENT, REGENERATION, AND RECIRCULATION SYSTEM WITHIN SMART HOME INFRASTRUCTURE. (Integrative Complex Water Purification Module for Smart Home Infrastructure Based on Multifunctional Electrochemical and Automated Water Treatment Technologies)

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Abstract

This article examines an integrative complex water purification module designed for the treatment of groundwater and water resources of similar quality in accordance with modern water supply standards and smart home infrastructure requirements. The proposed system is intended to provide automated multi-stage water purification, monitoring, and conditioning with a production capacity ranging from 1,500 to 3,000 gallons per day. Particular attention is devoted to the structural organization of sequential water treatment and monitoring units integrated into a unified technological cycle. The article describes the implementation of active monitoring systems based on electromagnetic resonance spectroscopy principles for real-time analysis of fundamental water quality parameters. The technological process includes primary sedimentation, gravitational separation, aeration, oxygen dissolution enhancement through an aerodynamic vortex foam generator, electrochemical processing, ion-exchange purification, and automated self-cleaning filtration systems.

The article further examines multifunctional electrochemical reactors equipped with water-permeable carbon–carbon electrodes capable of performing multiple electrochemical treatment operations without the use of chemical reagents. These operations include acidity level correction, disinfection, coagulation, flotation, and antibacterial treatment. Special consideration is given to the integration of sedimentation systems, contact grids, ion-exchange columns, and automated filtration modules into a coordinated infrastructure for continuous water regeneration and purification. It is concluded that the proposed integrative complex module represents a technologically advanced approach to water treatment infrastructure for smart homes and intelligent buildings, combining automated control systems, environmentally sustainable electrochemical technologies, and multifunctional purification processes into a unified high-efficiency ecosystem capable of meeting contemporary environmental, infrastructural, and operational requirements.

Keywords: *Smart home infrastructure; smart home infrastructure components; innovative smart home infrastructure components; innovative smart home infrastructure components for energy supply; innovative smart home infrastructure components for backup energy storage; innovative smart home infrastructure components for water supply, water treatment, regeneration, and recirculation; innovative smart home infrastructure components for clean air supply*

Integrative Multifunctional Water Regeneration, Treatment, and Recirculation System for Smart Home Infrastructure

Arrangement Scheme of Operational Modules in an Integrative Complex Water Purification Module at the Input of the Water Supply System

The integrative complex module, developed in accordance with the technical requirements of smart home infrastructure, is designed to treat groundwater and water resources of similar quality to the level required by modern water supply standards. The productivity of the integrative complex module ranges from 1,500 to 3,000 gallons per day.

The system includes a series of sequential water monitoring and treatment units. The process of passing through all stages of treatment and monitoring begins with a collector of all incoming water, in which comprehensive active monitoring of all fundamental water parameters is performed based on the principles of electromagnetic resonance spectroscopy.

After this stage, all water enters a sedimentation tank, the primary purpose of which is the initial sedimentation process and separation of the water flow into contaminated water containing sediment and water after gravitational sedimentation. The clarified water is supplied by means of a pump into a primary aeration column for aeration and maximum possible dissolution of oxygen in water, achieved through the operation of an aerodynamic vortex foam generator connected to a compressor.

After completion of the first aeration process and oxygen dissolution in water, part of the water together with foamed sediment is removed, while another part is directed into an electrochemical reactor with a multifunctional operational cycle and electrochemical cells equipped with water-permeable carbon–carbon electrodes.

From the electrochemical reactor, the treated water, processed in accordance with the specified multifunctional operational cycle, is directed into a sedimentation tank, where it is separated into two flows: one flow is discharged for disposal after the sedimentation section, while the second purified flow, processed through the combined multifunctional operational cycle of the electrochemical reactor cells and the contact grid of the sedimentation tank, is directed into ion-exchange purification columns.

After treatment in the ion-exchange purification columns, the purified water is directed into automatic self-cleaning filters, from which, after separation of sediment within the filters, the water is supplied into a second electrochemical reactor with a multifunctional operational cycle. The electrochemical reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents. Such operations include acidity level correction, disinfection, coagulation, flotation, and antibacterial treatment.

The water treated in this manner is then directed into aeration columns and forced oxygen dissolution columns, where oxygen is dissolved in water to the level of complete saturation. At the outlet of these columns, sediment and other foamed contaminants are separated from the main water flow and disposed of, while the remaining purified water is directed through a storage reservoir to end users.

The diagram designates the following components:

1 – reservoir into which water enters from the system or collector; this reservoir contains active online water contamination monitoring systems based on the principles of electromagnetic resonance spectroscopy (an invention of the project authors);

2 – primary sedimentation tank connected to pump 4 and equipped with a discharge line for sediment removal;

3 – compressor connected to aerodynamic foam generators in the columns for separation of sediment fractions and other contaminants;

4 – centrifugal pump with all necessary supporting infrastructure;

5 – column for aeration and oxygen dissolution in water, as well as for lifting foamed contaminants and organic matter into the upper section of the column;

6 – column for separation of foamed sediment and contaminants from the water mass;

7 – electrochemical reactor with a multifunctional operational cycle; the reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents, including acidity correction, disinfection, coagulation, flotation, and antibacterial treatment;

8 – non-contact water quality monitoring system controlled by a dedicated processor connected to sensor modules installed at corresponding pipeline sections and operating on the principles of electromagnetic resonance spectroscopy;

9 – ion-exchange treatment columns having a sectional structure; depending on productivity requirements, the column may contain one, two, or three sections; such a structure allows one column to contain three ion-exchange materials, including the natural ion-exchange material zeolite;

10 – sedimentation tank receiving discharge from the electrochemical reactor and from which clarified water is supplied by a pump to the inlet of ion-exchange treatment columns 9;

11 – automatic self-cleaning mechanical filters capable of being replaced with membrane-based automatic filters;

12 – pump supplying purified water from sedimentation tank 10 to the inlet of ion-exchange treatment columns 9;

13 – pump supplying purified filtered water from filters 11 into the second electrochemical reactor with a multifunctional operational cycle;

14 – electrochemical reactor with a multifunctional operational cycle; the reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents, including acidity correction, disinfection, coagulation, flotation, and antibacterial treatment;

15 – column for aeration and oxygen dissolution in water, as well as for lifting foamed contaminants and organic matter into the upper section of the column; an aerodynamic vortex foam generator is installed in the lower section of the column;

16 – column for separation of foamed sediment and contaminants from the water mass;

17 – innovative aerodynamic vortex foam generator, the inlet of which is connected to the compressor outlet;

18 – outlet and discharge line from column 6 used for separation of foamed sediment and contaminants from the water mass;

19 – discharge line for removal of sediment from sedimentation tank 10;

20 – discharge line for water treated in the electrochemical reactor into sedimentation tank 10; water in the electrochemical reactor may undergo several treatment operations without the use of chemical reagents, including acidity correction, disinfection, coagulation, flotation, and antibacterial treatment;

21 – reserve discharge line for sediment removal from automatic mechanical filters or their membrane filter equivalents;

22 – final storage reservoir for treated water before supply for consumption;

23 – reserve discharge line for removal of accumulated sediment and contaminants from the storage reservoir;

24 – discharge line from column 16 for separation of foamed sediment and contaminants from the water mass.

Figure 1.

In the specified configuration, all integrated modules are multifunctional and may be adjusted for operation with several types of source water supplied to the input of the integrative complex module.

For monitoring and control of the electrochemical reactors, the structure of the integrative complex module includes a control and management system functionally connected to non-contact electromagnetic resonance sensor modules operating on the principles of electromagnetic resonance spectroscopy.

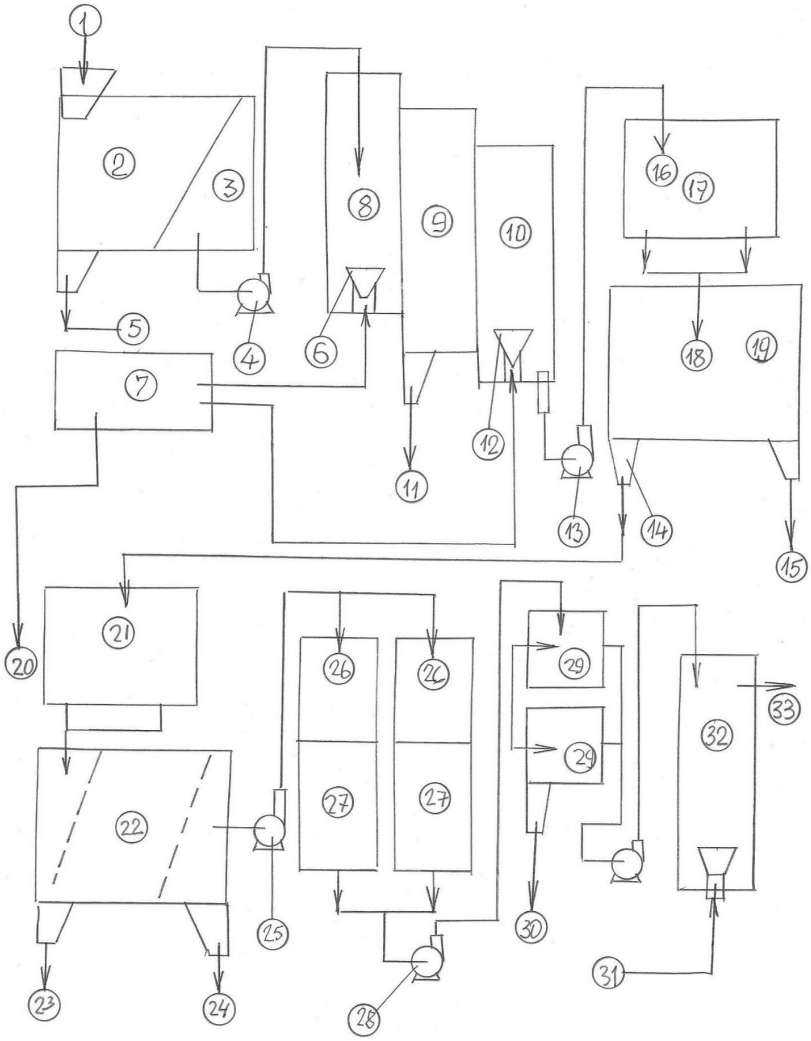
The specified system is capable of operating in a fully autonomous automatic cycle with complete monitoring of treatment results and water quality at all stages of the treatment process.

The specified system possesses a 100 percent level of operational flexibility and, during operation and configuration, is capable of changing the sequence and specific operational parameters depending on technical requirements and the characteristics of the integrated components and systems.

Example of an industrial modular system for water purification and regeneration using electrochemical methods.

Configuration with water regeneration for repeated reuse.

Figure 2.



Integrative complex module for water regeneration with preparation for recirculation; the entire regeneration process is performed without the use of chemical reagents.

The integrative complex multifunctional process for regeneration of water used at a single facility includes the following systems:

- input sedimentation without additional without additional processing;

- foam treatment with separation of sediment fractions and organic contaminants;
- separation of the foamed contaminant complex from contaminant-free liquid;
- repeated aeration of separated water with oxygen dissolution to the level of complete saturation;
- complex water treatment in an electrochemical reactor according to a multifunctional scheme, including acidity correction, disinfection, saturation with coagulants or flocculants, and return of water flows to a common acidity level;
- sedimentation within the discharge water flow containing coagulants or flocculants;
- repeated multifunctional treatment of the water flow from the sedimentation tank containing coagulants or flocculants according to the following final scheme: acidity correction, disinfection, and return of the entire treated water flow to a common acidity level;
- final sedimentation of all water treated in the second electrochemical reactor;
- treatment in ion-exchange processing columns, including sections containing natural granular zeolite instead of synthetic ion-exchange resin;
- treatment in automated self-cleaning mechanical filters or membrane filters;
- final aeration by means of aerodynamic vortex foam generation with oxygen dissolution to the level of complete saturation.

The diagram designates the following components:

1 – input sedimentation tank for formed sediment with functions for removal of formed sediment and transfer of clarified water to the next treatment stage;

2 – sedimentation section in tank 1;

3 – clarified water concentration section in tank 1;

4 – pump for transferring clarified water to subsequent treatment stages;

5 – system for removal of water containing formed sediment;

6 – aerodynamic vortex foam generator;

7 – compressor operating with three aerodynamic vortex foam generators;

8 – column for vortex foaming of clarified water;

9 – column into which foam from the upper section of column 8 is discharged, intended for aerodynamic vortex foaming of clarified water;

10 – column for vortex foaming, aeration, and saturation of treated water with dissolved oxygen to the level of complete saturation;

11 – discharge line for contaminants from column 9 receiving foam from the upper section of column 8;

12 – intermediate aerodynamic vortex foam generator;

13 – pump supplying water after treatment in column 10, with maximum air content and dissolved oxygen saturation, into the electrochemical cells of the first electrochemical reactor along the liquid flow path;

14 – discharge line for purified water after sedimentation following complex treatment in the first electrochemical reactor along the liquid flow path;

15 – contaminant discharge line from the sedimentation tank installed after the electrochemical reactor;

16 – water inlet into the electrochemical reactor cells after aeration and oxygen dissolution to the level of complete saturation;

17 – housing of the electrochemical reactor;

18 – discharge of water from the interelectrode space of the electrochemical reactor cells after completion of the treatment cycle;

19 – multifunctional sedimentation tank;

20 – outlet from compressor 7 to the inlet of the final aerodynamic vortex foam generator system;

21 – multifunctional electrochemical reactor for comprehensive final water treatment according to a multifunctional scheme, including acidity correction, disinfection, and return of the entire treated water flow to a specified common acidity level;

22 – multifunctional sedimentation tank;

23 – discharge line for contaminated liquid;

24 – reserve water discharge line from the clarified water section of the sedimentation tank;

25 – pump supplying water from the final section of the sedimentation tank to the segments of the ion-exchange columns;

26 – upper sections of the ion-exchange columns in which granular zeolite is used as the ion-exchange material;

27 – lower sections of the ion-exchange treatment columns containing ion-exchange resin;

28 – pump for transferring water after treatment in the ion-exchange purification columns into automated self-cleaning mechanical filters or membrane filters;

29 – system of automated self-cleaning mechanical filters with a pump for supplying filtered water into the final aeration and oxygen dissolution column to the level of complete saturation;

30 – sediment discharge line from the automated self-cleaning filters;

31 – final aerodynamic vortex foam generator;

32 – column for the final stage of aeration and oxygen dissolution in water to the level of complete saturation;

33 – regenerated water supply line for recirculation.

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PROTECTIVE ENCODING OF INFORMATION CARRIERS. (Protective encoding of information carriers, including optical discs and digital external information carriers)

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Abstract

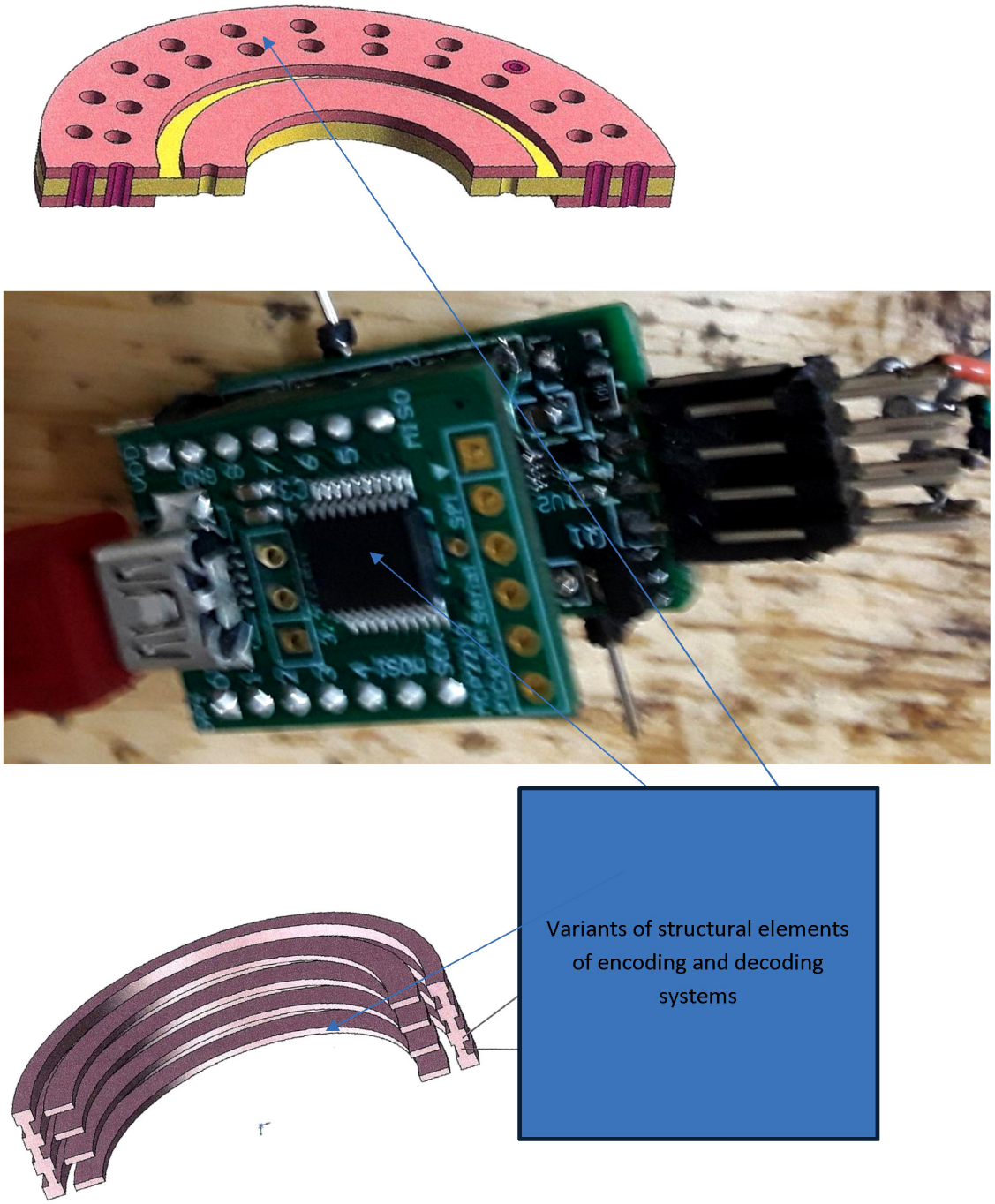
The article examines a technology for the protective encoding of information carriers based on the application of a coding coating and the subsequent identification of its parameters through resonance measurement methods. The proposed technical solutions are intended for the protection of optical discs and digital external information carriers, including single-layer and multi-layer optical storage systems. Special attention is given to the principles of encoding and decoding using electromagnetic resonance spectroscopy and impedance analysis, enabling non-contact identification and verification of coding elements with high sensitivity and accuracy.

The article describes the technological features of the system, including the possibility of selective three-dimensional encoding of multilayer optical discs, real-time monitoring of information carriers within corporate security infrastructures, and the creation of mobile or stationary sensor-based analytical devices. The advantages of the proposed technology over existing protection systems are considered, including flexible coding configurations, full production-line quality control, independence from optical drive systems, compatibility with different recording formats, and the possibility of integrating the technology into complex information security systems.

Additional attention is devoted to the practical application of the technology in corporate, industrial, scientific, medical, and military environments, as well as to issues of confidentiality and protection of sensitive information. The article also outlines the physical principles underlying the resonance method and impedance spectroscopy used for the identification and analysis of coding parameters in protected information carriers.

Keywords: *Encoding; Decoding; Protective encoding; Optical disc; Digital external information carriers; Film inspection; Identification of control parameters; Single-layer optical disc; Multi-layer optical disc; Electromagnetic resonance spectroscopy; Additional features and application possibilities; Additional devices and systems*

Figure 1.



Introduction:

General information

All projects of this group of technical solutions are based on a single method of encoding and subsequent identification of the recording of the encoding element.

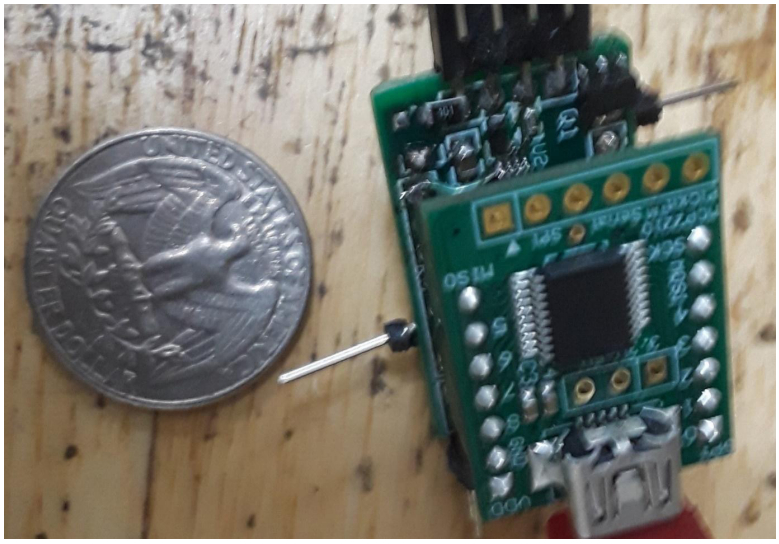
The essence of the principle consists in applying a coding coating or its technological equivalent onto the protected object and subsequently measuring the thickness of this coating, which determines the coincidence or non-coincidence of the measurement results with the code.

If the obtained result coincides with the established one, positive identification of the encoding element occurs; in the case of non-coincidence, negative identification occurs along with the stopping or blocking of the operating cycle of the equipment or the information consumer, for example, a computer.

Additional technological features.

Technologically, the issues related to the application of special coatings have been resolved, and this technology has been repeatedly tested in similar tasks associated with the control of film thickness on solar battery panels and in traditional semiconductor manufacturing.

Figure 2. *Electronic encoding module in the form of a microassembly*



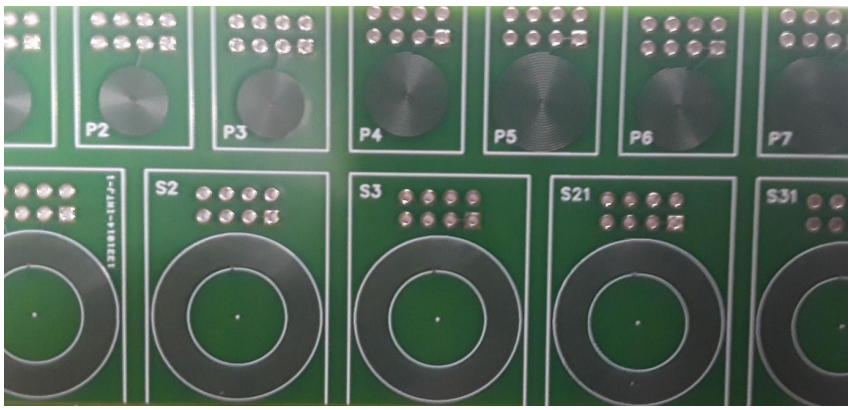
Scale factor of the encoding and decoding system

Additional features and possibilities for the application of the technology in relation to the new conditions that have emerged in the market of information carriers and storage devices during the last year.

In connection with the emergence of new recording and reading formats on optical information carriers using blue lasers, and in connection with the beginning of the production of multilayer optical discs based on the same technology, the proposed principles and technical solutions for protective encoding have acquired even greater significance, since the amount of recorded information on each disc is increasing and the absence of protection leads to ever greater losses of secret or confidential data.

In addition to the information already provided, it is necessary to indicate the possibilities for encoding each layer in multilayer discs, in which each level of the recording layers is encoded, which constitutes a significant improvement of the optical information carrier formatting system in three-dimensional form and serves as a means of ensuring (for especially important and secret information) local selective encoding of information within a single disc.

Figure 3. *Flat coils of encoding and decoding systems*



Organization of corporate protection systems

The proposed technology, when organizing a system for protecting information flows within a single corporation, provides protection at several system levels, including real-time monitoring of the condition and location of each disc available within the corporation.

When using the proposed encoding methods for protecting information on mobile external information carriers, it is assumed that the same advantages will be obtained as when applying them to optical information carriers and storage devices.

Changes in the structure and boundaries of use of the product created as a result of the project implementation

Thus, on the basis of similar solutions, it is possible to create at least two projects with a large number of applications in each: a technology project for encoding optical information storage devices in the form of discs, including a corresponding analytical-sensory device, which in turn may have numerous applications in various fields and industries; and a project for encoding and protecting information on mobile external information carriers, including a corresponding mobile or stationary sensory measuring-analytical-comparative device, also having numerous applications and design models.

Additional devices and systems that can be created on the basis of the same fundamental technological solutions

At the request of the project customer, the projects may include a section concerning additional devices by means of which the entire corporate system for the security and protection of information flows is formed within a single corporation or group of corporations or (according to Russian specifics, state corporations), as well as separate research institutions, academic institutes, and large healthcare institutions.

As a special product, an information protection system may be created not only in the field of storage but also in the operational field, during the transmission of commands and signals in the conditions of army units and formations and in the conditions of the Navy.

Under modern conditions, when information is concentrated in relatively very small sizes and volumes of storage devices, possible damage from unauthorized or criminal access to these arrays of information may be prevented or localized through the creation of a special infrastructure of the specified protection systems, which may be standardized within the specificity of a given ministry, main administration, or structural corporate associations and enterprises of a lower organizational level.

Information confidentiality

In more detail (in volumes exceeding the scope of this presentation and the illustrative materials attached to it), all necessary information may be provided upon the documentary and legal formulation of the intentions of a potential customer or partner, after the signing of confidentiality agreements with them (in a mutually agreed and acceptable legal form for both parties).

For a more complete understanding of the existing physical principles underlying the execution of encoding and decoding operations of optical discs, a magneto-resonance method has been applied, a brief description of which is provided below.

Brief description of the resonance method:

The method provides for the creation of an alternating electromagnetic field in the space in which the investigated sample is located. This field acts as an intermediary between the resonant circuit and the tested sample. On the one hand, the resonant circuit is the emitter (radiator) of this field, and on the other hand, it is the acceptor (sensitive element) of those changes in the electromagnetic field introduced by the tested sample.

Even in the absence of the tested sample, the alternating electromagnetic field created by the solenoid is the sum of two electromagnetic fields that change in antiphase relative to each other. One field is generated by the change in the magnetic induction of the solenoid and results in a vortex electric field (Maxwell-Faraday equation).

The other is generated by the change in the electric field created by the potential difference between the extreme turns of the solenoid most distant from each other (if the sample is placed inside the solenoid) or by the potential difference between the turn closest to the surface of the measured sample and the sample itself (if the sample is located opposite the end face of the solenoid), and results in a vortex magnetic field (Ampère's circuital law with Maxwell's correction).

Under the influence of the external alternating electromagnetic field, depending on the nature of the tested sample, such electrical phenomena as linear and vortex conduction currents, linear and vortex displacement currents, as well as linear and vortex ionic currents (ordered movement of ions) may be induced in the sample.

In accordance with the principle of field superposition, these electrical phenomena introduce distortions into the external alternating electromagnetic field. These distortions are perceived by the solenoid of the resonance sensor. The resonant circuit, which includes this solenoid, changes its behavior analogously to the way it would if additional elements such as a capacitor, inductance, and resistor were added to it. The combination of additional capacitive, inductive, and active resistance represents an additional impedance introduced into the system by the tested sample, and this attribute is measured by the resonance sensor.

Changes in the parameters of the resonant circuit are reflected in changes in its amplitude-frequency characteristic, namely, the resonant frequency and amplitude of the circuit change. By studying these changes, it is possible to judge the impedance of the investigated sample.

Principle of processing data obtained from resonance sensors

The resonance sensor makes it possible to determine the value of the total impedance of the investigated sample at the operating frequency of this sensor (see "Brief description of the resonance method"). By itself, this value is of little informational significance. However, everything changes fundamentally if a set of sensors with different operating frequencies is available.

In this case, it becomes possible to use a unique natural phenomenon observed in all types of substances: inorganic, organic, and biological. This phenomenon consists in the fact that a substance changes its specific impedance depending on the frequency of the electric field acting upon it, and this change depends on the composition of the investigated substance.

This phenomenon is studied and actively used by the rapidly developing scientific field known as Impedance Spectroscopy.

Impedance spectroscopy – A method for investigating various objects based on the measurement and analysis of the dependence of impedance on the frequency of alternating current. Different objects and processes are characterized by different dependences of active and reactive impedance on frequency, which makes it possible to solve the inverse problem – obtaining information about these objects and processes through the analysis of the frequency characteristics of their response to alternating current.

The fact that the change in impedance with a change in frequency depends on the composition of the substance makes it possible to identify the influence of each component on the total impedance of the substance at various frequencies. After determining the weighting coefficients of the influence of the corresponding components on the total impedance of the substance at each of the operating frequencies of the resonance sensors, it is possible, on the basis of the sensor readings and by solving a system of linear equations, to obtain information about the concentration of the investigated components.

The accuracy of this method is greatly influenced by the correct selection of the operating frequencies of the sensors. By scanning over a wide frequency range, it is necessary to determine the frequency regions most characteristic for each component, that is, the frequencies at which the component gives the greatest response.

Traditional impedance spectroscopy in its studies uses a source of alternating voltage that acts on the investigated sample by contact, while an electric current arises in the circuit, the magnitude and phase shift of which depend on the impedance of the sample.

The results are usually displayed in the form of Lissajous figures or Nyquist diagrams. In such studies, it is difficult to achieve high sensitivity and measurement accuracy.

The proposed methodology, in which impedance measurement is performed using resonant circuits, possesses significantly higher sensitivity and accuracy; moreover, it is non-contact.

There are certain technical difficulties in creating an oscillatory circuit with a resonance frequency tunable over a wide range, therefore traditional impedance spectroscopy will have to be used to search for the frequencies "characteristic" of the components.

After the characteristic frequencies are found and resonance sensors for these frequencies are created, the component monitoring system developed on the basis of these sensors will possess exceptional sensitivity and accuracy.

Interference immunity

Such "mechanical" parameters as VISCOSITY, DENSITY, TRANSPARENCY, PRESSURE (if the medium is incompressible) should not have any influence on the measured electrical parameters of the substance. FLOW VELOCITY IN THE PIPELINE and TURBULENCE – these phenomena are too slow to influence the "megahertz" impedance measurement processes. HARDNESS is a chemical indicator completely determined by the components contained in the substance. Temperature, as a rule, influences the value of impedance, but temperature measurement and its consideration during impedance measurement do not represent a complex technical task.

Advantages of the Proposed Technology Addressing the Essence of the Problems Identified in the Market of Optical Information Carrier Systems:

1. There are multiple variants of coding coating thicknesses, which make it possible to have numerous variants of the protection code, unlike existing technologies that have only one code variant;

2. During the coating application process, a control technology fully identical to the decoding technology is used, which makes it possible to completely control the quality of encoding during disc manufacturing without removing the disc from the conveyor, unlike existing technologies in which the disc must be removed from the conveyor and installed into a testing device for inspection; thus, control is selective in existing technologies, whereas in the proposed technology it is 100% control, which excludes the release of defective discs that in existing technologies are detected only during operation;

3. The proposed technology provides the possibility of encoding all categories and types of discs regardless of recording and reading format, unlike existing technologies in which encoding depends on the recording and reading format of the disc;

4. In the proposed technology, the coding coating may serve as the basis for a personal secret code or cipher, which is absent in existing technologies;

5. In the proposed technology, the decoding and identification sensor is mobile and may have several delivery variants, including an autonomous variant not connected to the disc drive, whereas in existing technologies the decoding system is installed only in disc drives; thus, the presence and correctness of encoding can be controlled only during installation of the disc into the drive, while in the proposed technology the code can be controlled and identified outside the disc drive, for example in stores or at the entrances of enterprises and institutions, which is especially important for ensuring a complete information confidentiality regime;

6. In the proposed technology, decoding excludes any dependence on the optical systems of the disc drive, but the decoding results may alter the operation of the optical systems, for example the servo drive for orientation and focus position control of the reading or writing laser, unlike existing technologies in which the decoding process completely depends on the optical elements of the disc drive, which complicates its design and sharply reduces reliability;

7. The proposed technology has several hierarchies of the fundamental operating scheme, possesses a flexible algorithm, and can be integrated into any security system of optical memory, including hybrid information carriers that, in addition to the optical component, also contain carriers built on other basic principles; existing technologies do not possess such flexibility;

8. The proposed technology makes it possible to use the disc code as an access password for entry into professional information arrays of the Internet, which existing technologies do not provide.

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GREEN AVIATION FUEL. (Applied developments of fully "green" aviation fuel, the publisher reports. Scientists and engineers have created fuel from "green" hydrogen and captured CO_2)

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Abstract

The article discusses approaches to the development of environmentally friendly aviation fuel based on "green" hydrogen and captured carbon dioxide, as well as the prospects for implementing Sustainable Aviation Fuel (SAF) in the context of aviation decarbonization. Special attention is given to cyclic carbon utilization technologies that enable the production of fuel chemically identical to conventional aviation kerosene without increasing atmospheric carbon concentration.

The article presents the design features and advantages of complex dynamic homogenization technology for hydrocarbon fuel mixtures and emulsions, enabling efficient mixing of components directly within the flow process. Applications of the system in various internal combustion engines, oil refining facilities, and fuel stations are considered.

The study demonstrates that this technology improves fuel mixture uniformity, reduces soot emissions, enhances combustion efficiency, and increases fuel performance while allowing integration without significant modifications to existing engines and industrial equipment.

Keywords: *Aviation fuel; Emulsion of green hydrogen and captured carbon dioxide; Applied developments of environmentally friendly aviation fuel; Fuel that is chemically identical to kerosene but does not increase carbon concentration in the atmosphere; Aviation is one of the most difficult industries to decarbonize; Renewable fuel; A product of a fully circular carbon use cycle; Hydrocarbon fuel mixtures*

Possible Applications of Complex Dynamic Homogenization Technology for Hydrocarbon Fuel Mixtures in Internal Combustion Engines

Design Advantages of the Device for Dynamic Homogenization and Dynamic Formation of a Mixture or Emulsion in the Flow of Its Components.

The device for dynamic online homogenization and dynamic formation of a mixture or emulsion within the flow of its components has minimal dimensions and a simple geometric shape in the form of a regular cylinder (for example, a device with a capacity of 50 gallons of emulsion per hour has a diameter of only 37 millimeters and a total length of only 150 millimeters).

The device can be manufactured in any required scale factor.

Figure 1. *Device for Fuel Mixture Homogenization*

Types of Internal Combustion Engines in Which Complex Dynamic Homogenization Technology for Fuel and Fuel Mixtures Can Be Applied.

The dynamic homogenization system has minimal dimensions and an optimal geometric shape.

The liquid inlets to the system and the outlets for the homogenized liquid are completely standardized; therefore, the dynamic fuel mixture homogenization system can be installed on any internal combustion engine.

Modern engines equipped with a high-pressure pump can be fitted with a dynamic fuel mixture homogenization system without requiring any modifications to the fuel system.

The dynamic homogenization system can be installed both on stationary internal combustion engines and on internal combustion engines used in vehicles.

The dynamic homogenization system may be equipped with an additional system for the formation of two types of fuel emulsions: compressible emulsions and incompressible emulsions.

The dynamic homogenization system enables the efficient introduction of up to eight additional components into the emulsion.

Without modification, the dynamic homogenization system can effectively dissolve combustible gases in the flow of liquid hydrocarbon fuel before injection into the combustion chamber, both in stationary internal combustion engines and in engines installed in vehicles.

Types of Liquid Hydrocarbon Fuels That Can Be Subjected to Dynamic Homogenization.

Any type of liquid hydrocarbon fuel can be processed using dynamic homogenization technology.

Any types of fuel mixtures based on gasoline, all types of diesel fuel, and fuel oil can be processed using dynamic homogenization technology.

Any types of liquid biofuels can be processed using dynamic homogenization technology.

Any types of biological fuel compositions can be processed using dynamic homogenization technology**.**

Dynamic homogenization of fuel without impurities

In liquid hydrocarbon fuels, fuel clumps may form during storage, which can subsequently cause problems with fuel injection and uniform combustion.

The higher the fuel viscosity, the greater the probability of the formation of clumps and other types of fuel non-uniformities.

The dynamic fuel homogenization system is installed in the engine fuel system on the fuel pipeline between the engine fuel pump and the engine high-pressure pump.

As the fuel passes through the dynamic homogenization system, homogenization occurs within the flow according to the turbulence level, after which the process of dynamic homogenization is completed

in the high-pressure pump in terms of volume and dimensional scale within a three-dimensional coordinate system.

The operation of the dynamic fuel homogenization system does not require any additional energy sources or additional structural elements.

The dynamic fuel homogenization system can also be used in homogenization processes and equipment in parallel with fuel recirculation in storage tanks during fuel production and fuel storage at filling stations.

Dynamic homogenization of gasoline-based fuel mixtures

Fuel mixtures based on gasoline, such as gasoline-ethanol mixtures and gasoline-methanol mixtures, may experience the effect of gravitational separation of water from the hydrocarbon portion of the fuel mixture during long-term storage.

The dynamic homogenization system in gasoline engines using a mixture of gasoline and ethanol or a mixture of gasoline and methanol as fuel is installed between the fuel pump and the engine high-pressure pump.

As the fuel mixture, in which water has separated from gasoline, passes through the dynamic homogenization system, homogenization occurs within the flow according to the turbulence level, after which the process of dynamic homogenization is completed in the high-pressure pump in terms of volume and dimensional scale within a three-dimensional coordinate system.

During the homogenization process, water in the form of microdroplets is uniformly distributed throughout the volume of the hydrocarbon fuel mixture, after which the specified mixture is transformed into a micro- or nanoscale emulsion.

According to the test results of the emulsion obtained using the dynamic homogenization system, the soot concentration in exhaust gases is reduced by 97%, while the level and rate of heat release increase by at least 35%.

The installation of the dynamic homogenization system on a gasoline engine does not require any additional original components, and no structural modifications to the engine are required.

Dynamic homogenization of diesel fuel-based mixtures

The preparation of fuel mixtures consisting of diesel fuel and ethanol or methanol is extremely difficult due to the large difference in viscosity between these materials.

The dynamic fuel mixture homogenization system can prepare a high-quality and homogeneous mixture of diesel fuel and ethanol or methanol within fractions of a second, directly in the pipeline and in any required proportion.

The dynamic homogenization system in diesel engines using a mixture of diesel fuel and ethanol or a mixture of diesel fuel and methanol as fuel is installed between the fuel pump and the diesel engine high-pressure pump.

As the fuel mixture, in which water has separated from the fuel, passes through the dynamic homogenization system, homogenization occurs within the flow according to the turbulence level, after which the process of dynamic homogenization is completed in the high-pressure pump in terms of volume and dimensional scale within a three-dimensional coordinate system.

During the homogenization process, water in the form of microdroplets is uniformly distributed throughout the volume of the hydrocarbon fuel mixture, after which the specified mixture is transformed into a micro or nanoscale emulsion.

According to the test results of the emulsion obtained using the dynamic homogenization system, the soot concentration in exhaust gases is reduced by 97%, while the level and rate of heat release increase by at least 35%.

The installation of the dynamic homogenization system on a diesel engine does not require any additional original components, and no structural modifications to the engine are required.

Dynamic homogenization of heavy diesel fuel-based mixtures

The preparation of fuel mixtures consisting of heavy diesel fuel and ethanol or methanol is extremely difficult due to the large difference in viscosity between these materials.

The dynamic fuel mixture homogenization system can prepare a high-quality and

homogeneous mixture of heavy diesel fuel and ethanol or methanol within fractions of a second, directly in the pipeline and in any required proportion.

The dynamic homogenization system in heavy diesel engines using a mixture of heavy diesel fuel and ethanol or a mixture of heavy diesel fuel and methanol as fuel is installed between the fuel pump and the engine high-pressure pump (if such a pump is included in the engine design). If a high-pressure pump is not part of the engine, the dynamic homogenization system is installed on the fuel pipeline after the fuel pump.

As the fuel mixture, in which either water has separated from the heavy diesel fuel or clumps of heavy diesel fuel have formed, passes through the dynamic homogenization system, homogenization occurs within the flow according to the turbulence level, after which the process of dynamic homogenization is completed in the high-pressure pump or in the injectors in terms of volume and dimensional scale within a three-dimensional coordinate system.

During the homogenization process, water in the form of microdroplets is uniformly distributed throughout the volume of the hydrocarbon fuel mixture, after which the specified mixture is transformed into a micro- or nanoscale emulsion.

According to the test results of the emulsion obtained using the dynamic homogenization system, the soot concentration in exhaust gases is reduced by 97%, while the level and rate of heat release increase by at least 35%.

The installation of the dynamic homogenization system on an engine using heavy diesel fuel does not require any additional original components, and no structural modifications to the engine are required.

Dynamic homogenization of fuel oil-based fuel mixtures

The preparation of fuel mixtures consisting of fuel oil and ethanol or methanol is extremely difficult due to the large difference in viscosity between these materials and because of the non-uniformity of fuel oil.

The dynamic fuel mixture homogenization system can prepare a high-quality and homogeneous mixture of fuel oil and ethanol or methanol within fractions of a second, directly in the pipeline and in any required proportion.

In cases of an especially high level of fuel oil non-uniformity, the structural simplicity of the system allows its staged use with the formation of a gradual (step-by-step) sequential process for preparing a fuel oil-based fuel mixture.

The dynamic homogenization system in large engines using a mixture of fuel oil and ethanol or a mixture of fuel oil and methanol as fuel is installed between the fuel pump and the subsequent element of the engine fuel system.

As the fuel mixture, in which water has separated from the fuel oil or in which clumps and lumps have formed within the fuel oil flow, passes through the dynamic homogenization system, homogenization occurs within the flow according to the turbulence level, after which the process of dynamic homogenization is completed in the nozzle or injector in terms of volume and dimensional scale within a three-dimensional coordinate system.

During the homogenization process, water in the form of microdroplets is uniformly distributed throughout the volume of the hydrocarbon fuel mixture, after which the specified mixture is transformed into a micro- or nanoscale emulsion.

According to the test results of the emulsion obtained using the dynamic homogenization system, the soot concentration in exhaust gases is reduced by 97%, while the level and rate of heat release increase by at least 35%.

The installation of the dynamic homogenization system on the specified engine does not require any additional original components, and no structural modifications to the engine are required.

Preparation of fuel mixtures at oil refining facilities

At oil refining facilities, the system for dynamic homogenization of hydrocarbon liquids must include a high-pressure pump operating on the principle of a diesel engine high-pressure pump.

The specified integrated system can be used as a pump for mixing fuel mixture components or as a system ensuring fuel mixture recirculation in storage tanks.

The installation of such systems can be carried out on existing equipment without redesign or modernization; however, in this case, the system must include pumps for supplying mixture components into the system.

One of the possible applications of the dynamic homogenization system at oil refining facilities is the formation of a fuel mixture during the supply of fuel mixture components into a transport tank. Since the preparation time of the fuel mixture within the system is only fractions of a second, preparing the mixture during transfer into a transport tank eliminates the need for special storage tanks for fuel mixtures at the facility.

Preparation of fuel mixtures at fuel stations

At fuel stations, the system for dynamic homogenization of hydrocarbon liquids must include a high-pressure pump operating on the principle of a diesel engine high-pressure pump.

The specified integrated system can be used as a pump for mixing fuel mixture components or as a system ensuring fuel mixture recirculation in storage tanks.

The installation of such systems can be carried out on existing equipment without redesign or modernization; however, in this case, the system must include pumps for supplying mixture components into the system.

One of the possible applications of the dynamic homogenization system at fuel stations is the formation of a fuel mixture during the supply of fuel mixture components directly into the fuel tank of a vehicle or other transport unit. Since the preparation time of the fuel mixture within the system is only fractions of a second, preparing the mixture during transfer into the vehicle fuel tank eliminates the need for special fuel mixture storage tanks at the facility.

Preparation of fuel mixtures directly within the internal combustion engine system

If a vehicle can be equipped with an additional tank for the second component of the fuel mixture, the preparation of the fuel mixture can be carried out by the dynamic homogenization system directly within the fuel pipeline.

The feasibility of this approach was tested on a production diesel engine, and during this test a water-in-oil fuel emulsion was produced, i.e., diesel fuel was emulsified using ordinary tap water.

As a result of using such an emulsion, the soot concentration in exhaust gases was reduced by 97% (mixing proportions in the emulsion: 20% water and 80% diesel fuel).

Installation of the dynamic homogenization system on a newly manufactured internal combustion engine

The installation of the dynamic homogenization system on a newly manufactured internal combustion engine does not require any new elements in the engine design.

The system is installed into the fuel pipeline after the fuel pump, and its outlet is connected to the inlet of the high-pressure pump or, in the absence of such a pump, to the inlet of the structural element following the fuel pump.

Installation of the dynamic homogenization system on a retrofitted internal combustion engine

The installation of the dynamic homogenization system on a repaired or modified internal combustion engine does not require any new elements in the engine design.

The system is installed into the fuel pipeline after the fuel pump, and its outlet is connected to the inlet of the high-pressure pump or, in the absence of such a pump, to the inlet of the structural element following the fuel pump.

Installation of the dynamic homogenization system on industrial facilities for fuel mixture production

The system can be supplied by the manufacturer in a modular configuration.

The system composition and its functions can be modified by the manufacturing company without additional design work.

The system has no limitations or elements that would prevent its installation on any industrial equipment.

Installation of the dynamic homogenization system on fuel mixture tanks at fuel stations

The system can be supplied by the manufacturer in a modular configuration and can be manufactured in any required scale factor.

The system composition and its functions can be modified by the manufacturing company without additional design work.

Figure 2. *Device for Dynamic Emulsion Preparation*

The system has no limitations or elements that would prevent its installation on any industrial equipment.

The device for dynamic homogenization of liquid fuel and fuel mixtures can be used to perform technological homogenization before introducing the fuel or fuel mixture flow into processing equipment for the production of other hydrocarbon products.

As can be seen from the presented photographs, the dimensions of the device are very small in relation to its performance (the images show devices with a capacity of 1000 liters per hour).

Original Device for Dynamic Homogenization

A device for the dynamic homogenization of liquid fuels and fuel mixtures has been developed, manufactured, and repeatedly tested.

All elements and components of the device are manufactured using standard computer numerical control (CNC) machines without the use of special technologies or specialized cutting tools.

Stainless steel is used as the structural material, which allows the installation of the device and systems incorporating it in more corrosion-aggressive environments, such as marine vessels.

Figures 3, 4, and 5. Device for Dynamic Preparation of Fuel Emulsion in Disassembled Form

a)

b)

c)

The device is extremely compact and has dimensions that allow it to be integrated into virtually any internal combustion engine, both stationary types (for example, marine engines) and engines installed in vehicles (for example, all types of automobiles).

The device does not require any additional elements or components for operation and can be installed directly on the fuel pipeline of an internal combustion engine, after the fuel pump and before the engine high-pressure pump.

All input and output connection elements of the device are standardized. No special preparation, tools, or equipment are required for installing the device on an internal combustion engine.

The device has no moving parts and can be manufactured in any required dimensional scale factor.

The device can be manufactured using standard serial production equipment with computer numerical control (CNC); no special technologies, materials, or tools are required for the manufacturing, assembly, or quality control of the device.

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CHARACTERISTICS OF HIGH-RISE MIXED-USE BUILDINGS RELATED TO FIRE PREVENTION ORGANIZATION IN VIETNAM

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Abstract

High-rise mixed-use buildings in Vietnam are increasingly being constructed and developed to meet the needs of society, especially in urban areas. This article focuses on presenting the research results of the characteristics of high-rise mixed-use buildings related to fire prevention organization, as well as proposing and orienting some solutions and measures to contribute to improving the effectiveness of fire prevention organization for high-rise mixed-use buildings in Vietnam in the future.

Keywords: *High-rise mixed-use buildings; fire prevention and control organization; fire prevention and fighting*

1. Introduction

In Vietnam today, especially in large cities, the trend of constructing high-rise mixed-use buildings is becoming a smart and inevitable solution, closely linked to the speed of urbanization, the development of science and technology, and the needs of modern living. High-rise mixed-use buildings are multi-functional buildings that integrate various functions such as housing, offices, hotels, shopping centers, and public services within a continuous architectural whole. This model not only solves the problem of limited land in large cities but also simultaneously meets many material and spiritual needs of people in the same living and working space. From an economic and social perspective, this type of building allows for the optimization of land use value, promotes the growth of services and commerce, and creates an integrated, multi-utility living environment for urban residents. According to a report by the Fire Prevention, Fighting, and Rescue Police Department of the Ministry of Public Security of Vietnam, by the end of 2025, Vietnam will have 748 high-rise mixed-use buildings, a 26.4% increase compared to 2016, reflecting the rapid development of this type of building. In practice, when a fire occurs in a high-rise mixed-use building, firefighting and rescue efforts face numerous difficulties due to the multi-functional nature, complex structure, and large scale of the building. These difficulties not only hinder fire control but also result in loss of life, serious damage to property, infrastructure, business op-

erations, and even long-term impact on the morale of the local community. According to statistics, from 2016 to the end of 2025, the number of fires in high-rise mixed-use buildings in Vietnam was 176 (accounting for 0.87%), resulting in 16 deaths (accounting for 1.69%), 56 injuries (accounting for 1.28%), and estimated property damage of about 8,790.12 million VND (13). Given this situation, there are requirements to ensure fire safety and rescue for high-rise mixed-use buildings, including the urgent need to study the characteristics of high-rise mixed-use buildings in order to have solutions and measures to prevent fires and explosions in high-rise mixed-use buildings.

2. Research results

2.1. Architectural and Structural Characteristics of High-Rise Mixed-Use Buildings

— Architectural Characteristics of High-Rise Mixed-Use Buildings

The most fundamental architectural characteristic of high-rise mixed-use buildings is the vertical development of the structure. These are high-rise buildings that combine multiple functions within a single architectural whole, commonly including: a commercial and service base, office floors, hotels, and apartment blocks above. This leads to the concentration of a large number of people, assets, and activities in a limited horizontal space. Vertical development means that fire hazards (heat, smoke, toxic gases) affect multiple floors simultaneously, no longer confined to a small space as with low-rise buildings. This multi-functional integration creates a complex, interconnected vertical architectural space, making high-rise mixed-use buildings more fire-prone than single-function high-rise buildings.

In terms of architectural spatial organization, high-rise mixed-use buildings are typically divided into stacked functional blocks, each with different usage characteristics, fire load, and population density. Commercial and service blocks on the lower floors often concentrate a large number of people, use many flammable finishing materials, store diverse goods, and have high-power heat sources and electrical equipment. Meanwhile, office and hotel blocks have a more stable population density but longer stays, while apartment blocks on the upper floors are for regular living and have a diverse user base, including the elderly and children. This difference leads to inconsistent evacuation, rescue, and fire safety requirements for each area, making it difficult to organize a comprehensive and safe architectural solution. Vertical movement via staircases prolongs evacuation time, especially when users have to move from upper floors to the ground. In conditions of smoke, limited visibility, and panic, the chances of safe evacuation are significantly reduced. This is a crucial architectural principle – a requirement that high-rise buildings must be equipped with protected escape solutions, such as smoke-free stairwells, buffer lobbies, refuge floors, or equivalent solutions.

Mixed-use high-rise buildings are typically organized with a concentrated traffic and technical core, including stairwells, elevators, electrical and water shafts, and ventilation shafts. Architecturally, this core optimizes usable space and ensures a rational floor plan. However, from a fire safety perspective, the core is the most sensitive area, posing a potential risk of becoming a “smoke and fire conduit” if not properly protected. If stairwells are not properly positioned, separated by fire-resistant structures, and lack smoke control solutions, they will quickly be infiltrated by smoke, rendering them unusable as escape routes. This is especially dangerous for high-rise buildings, where stairwells are almost the only escape route...

— Structural Characteristics of High-Rise Mixed-Use Buildings

High-rise mixed-use buildings must withstand large and diverse loads, with wind and earthquake loads increasing significantly with height. Therefore, the structural system is usually a monolithic reinforced concrete structure, a composite structure, or a steel structure, with solutions such as frame-core, frame-wall, or central load-bearing core.

In fire conditions, high temperatures rapidly reduce the load-bearing strength of concrete and steel, especially for components not protected against fire. If the structure does not meet the required fire resistance limit, the risk of local instability and conductive collapse is very high, directly threatening the safety of evacuees and firefighters.

High-rise building structures have a high degree of continuity, with columns, walls, and load-bearing cores extending throughout the entire height of the building. When a fire occurs on one floor, the reduction in the load-bearing capacity of that floor's structure can have a chain reaction affecting the floors above and below, compromising the overall safety of the building. Therefore, the structure of high-rise buildings must not only meet normal load-bearing requirements but also maintain stability during a fire, sufficient to ensure the safe evacuation of occupants and the deployment of firefighting forces.

In high-rise buildings, structural elements such as floors, walls, partitions, and rigid cores simultaneously act as fire-resistant partitions to divide the building into fire compartments horizontally and vertically. Especially for mixed-use high-rise buildings, fire compartmentation vertically is a mandatory requirement to limit the scale and spread of the fire. If the fire-resistant structure does not meet the fire resistance limit, or is penetrated by pipes or technical cables without proper treatment, the effectiveness of fire compartmentation will be rendered ineffective...

2.2. Functional Layout Characteristics of Mixed-Use High-Rise Buildings

Mixed-use high-rise buildings are a type of high-rise structure that integrates various functions such as residential, office, hotel, shopping center, and public services within a single, interconnected architectural complex. Although these functions coexist within a single building, each functional area has different fire hazard characteristics. The basic characteristics of this type of building are its large construction scale, high population density, and large volume of flammable materials, goods, and substances, significantly increasing the risk of fire and explosions and the complexity of fire prevention and firefighting.

Commercial and service areas typically attract large crowds during the day, contain many flammable goods and materials, and the main fire risk is related to the electrical system. Fires often occur at night when the building is closed; however, due to their location on lower floors, these areas have the advantage of easy access to the outside space and convenient evacuation routes. Office spaces are typically located on intermediate floors, featuring open workspaces and escape routes centered around the building's core. Apartment buildings, on the other hand, are usually situated on higher floors with high population density and a diverse population including the elderly, children, and those with mobility impairments, making evacuation and rescue efforts in the event of a fire more challenging.

Furthermore, high-rise mixed-use buildings often have multiple basements and podiums housing fire-hazardous functions such as parking garages, substations, warehouses, and garbage disposal areas. In the event of a fire in a basement, the flames spread rapidly, producing a large amount of toxic smoke and spreading to upper floors through stairwells, ventilation shafts, and technical systems, posing a serious threat to the entire building.

2.3. Characteristics of the Technical Systems of High-Rise Mixed-Use Buildings

High-rise mixed-use buildings are equipped with many complex technical systems such as electrical systems, substations, generators, central gas systems, ventilation and air conditioning systems, and automatic fire alarm and extinguishing systems. A malfunction or improper operation of any one of these systems can lead to serious fire and explosion risks.

Most high-rise mixed-use buildings must be equipped with automatic fire alarm systems, automatic fire extinguishing systems, smoke protection systems, indoor and outdoor fire water supply systems, emergency lighting systems, escape route signage, and fire-fighting elevators in accordance with current regulations and standards.

In modern buildings, the Building Management System (BMS) plays a central role in monitoring, controlling, and interconnecting technical systems, especially the fire protection system. When a fire occurs, the BMS receives signals from the fire alarm system and automatically activates emergency scenarios such as cutting off power to the fire area, controlling elevators to a safe floor, activating the pressurization and smoke extraction system, controlling fire doors and fire extinguishing systems, contributing to reducing response time and improving the efficiency of evacuation and firefighting.

2.4. Characteristics of Flammable Materials, Heat Sources, and Fire Spread Potential in High-Rise Mixed-Use Buildings

The flammable materials present in high-rise mixed-use buildings are diverse, varied, and highly fire-hazardous. Many different types of flammable materials are always present in high-rise mixed-use buildings, depending on the nature and function of the building. The main flammable materials are paper and paper products; wood and wood products; fabrics and cotton and fiber materials; gasoline, oil, and gas; rubber and rubber products; synthetic resins and polymer derivatives... This further increases the risk of fire and explosion and complicates firefighting and rescue operations in high-rise mixed-use buildings.

The heat sources that can cause fires in high-rise mixed-use buildings are very diverse. The main sources of heat causing fires in high-rise mixed-use buildings originate from electrical systems, open flames in daily life, production and business activities, metal welding and cutting, and violations of fire safety regulations. In many cases, improper use of the electrical system, contrary to its original design, leads to overloading, short circuits, and fires.

The spread of fire and smoke and toxic gases in mixed-use high-rise buildings is very rapid. Fires can spread through inter-floor technical systems such as elevator shafts, ventilation ducts, cable trays, technical pipes, and structural openings. When a fire occurs, toxic smoke can spread into stairwells within minutes, rendering escape impossible if effective smoke protection measures are not in place.

2.5. Characteristics of the Electrical System in High-Rise Mixed-Use Buildings

Complex Load Classification: Due to the presence of various business and residential activities within the same building, the electrical system must be clearly separated, specifically as follows: Service/Commercial Electricity: shopping malls, supermarkets (high power, concentrated). Office Electricity: lighting systems, power outlets for office design. Apartment Electricity: personal living systems. Public Electricity: elevators, water pumps, corridor lighting.

Extremely High Reliability and Safety: Backup Power: always has a backup generator (capacity usually meets 100% of priority loads such as elevators, fire pumps, emergency lighting). ATS System: automatically switches power between the grid and the generator in case of a fault. Fire Safety: uses fire-resistant (FR) or flame-retardant (LSZH) cables for emergency systems.

Vertical structure (Busway): Instead of traditional cabling, high-rise buildings often use a Busway system (electrical conductors) running along the technical axis. Busways save space, handle heavy loads, and allow easy connection (L-off) at each floor.

Building Management System (BMS): The electrical system is often integrated with the BMS for remote monitoring: tracking electricity consumption, controlling smart lighting to save energy, and automatically shutting off power to non-priority areas in case of fire.

Grounding and lightning protection system: Due to the high height, buildings are required to have extremely strict direct lightning protection and surge protection (SPD) systems to protect sensitive electronic equipment inside.

Transformer substation (TBA): Usually located in the basement or technical floor. For high-rise buildings, TBAs are often dry-type transformers to minimize the risk of fire and explosion compared to oil-filled transformers.

2.6. Characteristics of Traffic and Water Sources

High-rise mixed-use buildings (combining apartments, offices, shopping centers, services, etc.) are large-scale and have a high population density. Therefore, traffic conditions and water sources for firefighting have unique characteristics that directly impact the effectiveness of firefighting and rescue operations. Specifically: high-rise mixed-use buildings are often constructed in urban centers and densely populated residential areas, which can easily lead to: traffic congestion during peak hours; encroachment on roads and sidewalks for business and parking; limited turning space; and the need for access roads for fire trucks: ensuring sufficient width, turning radius, and road load capacity to accommodate specialized fire trucks

(ladder trucks, pump trucks, rescue vehicles). Access to multiple sides of the building is required: for high-rise mixed-use buildings, access roads for fire trucks are needed on at least one or more sides (prioritizing the side with stairwells, main entrances, and technical areas).

For mixed-use high-rise buildings, the water tank must contain enough water to supply the entire fire hydrant system, automatic sprinkler system, and outdoor fire extinguishing system for at least 3 hours. Firefighting water can be shared with domestic water, but technical measures (partitions, suction pipe elevation) must be in place to ensure that domestic water never contaminates the firefighting water reserve. In addition to underground tanks, mixed-use high-rise buildings often have rooftop water tanks to create initial hydrostatic pressure and support immediate fire suppression in the first few minutes before the pumps reach maximum capacity. The building must have water inlet points located on the street so that professional fire trucks can directly pump water from outside into the building's piping system when the internal water reserve runs out.

3. Some directions for further research to contribute to improving the effectiveness of fire prevention work for high-rise mixed-use buildings

Through research, the following directions are drawn:

1) Proactively advise, propose, and improve legal regulations on fire prevention, firefighting, and rescue, and develop programs and plans for organizing fire prevention work for high-rise mixed-use buildings;

2) Strengthen leadership and guidance in organizing fire prevention work for high-rise mixed-use buildings;

3) Organize the development of plans, programs, and content for disseminating and educating knowledge and laws on fire prevention, firefighting, and rescue, and build a movement for all citizens to participate in fire prevention and firefighting activities for high-rise mixed-use buildings;

4) Strictly implement the process of organizing design appraisal and inspection of fire prevention and firefighting acceptance work for high-rise mixed-use buildings;

5) Improve the quality of organizing inspection and handling of administrative violations related to fire prevention and fighting for high-rise mixed-use buildings;

6) Organize and build a fire prevention, fighting and rescue force at the grassroots level and provide training and professional development in fire prevention, fighting, rescue and relief for high-rise mixed-use buildings;

7) Consolidate the organizational model, build a team of officers and equip the Fire Prevention, Fighting and Rescue Police force with means to serve the organization of fire prevention work for high-rise mixed-use buildings;

8) Promote preliminary and final reviews, research, application of science and technology, digital transformation and coordination to serve the organization of fire prevention work for high-rise mixed-use buildings.

4. Conclusion

The study of the characteristics of high-rise mixed-use buildings is of significant importance, contributing to ensuring fire safety and rescue in high-rise mixed-use buildings in Vietnam today. Given the current situation regarding the construction, development, and operation of high-rise mixed-use buildings, as well as the current fire and explosion situation, the Fire and Rescue Police force of the Ministry of Public Security of Vietnam, under the direction of various levels and sectors, has performed well in this area, contributing to minimizing fire incidents. However, this work still has limitations that need to be overcome. Furthermore, although there have been studies on this topic, there is a lack of systematic and in-depth research specifically on high-rise mixed-use buildings. Therefore, choosing this issue for research is necessary. This preliminary study proposes a system of guidelines to improve the effectiveness of fire prevention and control in high-rise mixed-use buildings in Vietnam.

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PRODUCTION REPEATABILITY IN SANDBLASTING: WHAT MAKES STABLE RESULTS POSSIBLE IN SMALL AND LARGE PRINT RUNS

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Abstract

This article discusses the repeatability of the sandblasting production process, which is key to achieving stable results for both small and large print runs. It examines the technological factors affecting engraving quality: layout preparation, stencil selection and fixation, abrasive properties, pressure, nozzle-to-surface distance, jet impact angle, and equipment condition. Special attention is paid to the contractor's role, quality control, defect prevention, and documentation of processing parameters. In conclusion, it is stated that achieving sustainable sandblasting results requires technological discipline, careful material preparation, standardized operations, and regular finished product monitoring.

Keywords: *sandblasting, abrasive treatment, production repeatability, stencil, quality control, process chart, result stability, small print runs, large print runs*

Relevance of the study

The relevance of this study is related to the fact that sandblasting is a method of abrasive surface treatment, in which the appearance of the product largely depends on the accuracy of the preparation of the layout, the quality of the stencil, the properties of the abrasive used, and the stability of the processing mode. In open technical sources, the process of glass sandblasting is described as a sequence of the following operations: creating an image in a special computer program, making a stencil, fixing it to the surface, and then exposing the abrasive material to the exposed areas of the product. Thus, the result of engraving is achieved not by chance, but by precisely performing a number of repetitive technological actions. Violation of any of these steps can lead to uneven depth, clarity, and uniformity of the engraving.

This topic is especially relevant for the production of small and large-scale prints. In the first case, the customer usually seeks to obtain a unique product made with a high degree of accuracy. In the second case, it is required to create a series of products with identical visual and technical characteristics. That is why production repeatability not only demonstrates quality but also becomes a key factor in the economic sustainability of the process. It helps to reduce the number of defects, minimize the cost of reworking products, and ensure a predictable result for the customer.

The practical significance of this topic lies in the fact that the parameters of the abrasive treatment have a significant impact on the surface quality. In research on jet abrasive processing, among the most important factors are the type of abrasive, pressure, working distance to the surface, and the angle of impact of the jet. These parameters are closely related to changes in the roughness of the treated surface. Thus, to ensure stable sandblasting, it is necessary not only to have the appropriate equipment but also to accurately observe fixed technological modes. This is especially true when re-manufacturing identical products.

The purpose of the study

The purpose of this study is to determine the conditions and technological aspects that ensure stable sandblasting results for both small and large print runs.

Materials and research methods

The study analyzed open technical data on sandblasting and abrasive blasting, as well as information on the use of stencil materials and practical parameters affecting the quality of engraving.

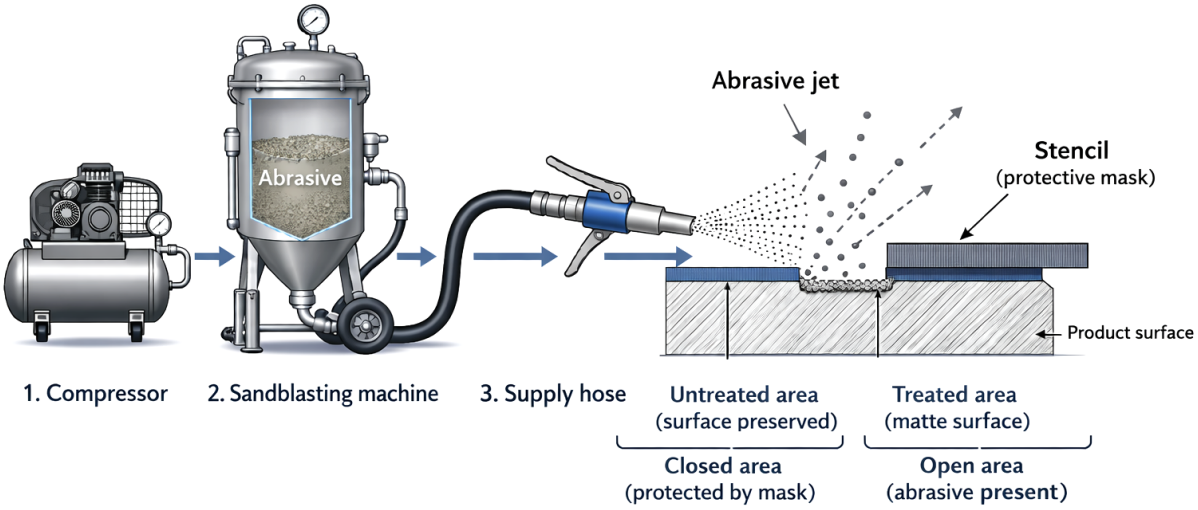
The methods of process analysis, comparison of conditions for small and large print runs, systematization of factors affecting repeatability, and generalization of quality control and defect prevention methods were applied in the work.

The results of the study

Sandblasting is a process in which a stream of abrasive particles is directed at the surface of a product. The technical description of this method states that the abrasive flow is supplied using compressed air or water. This flow can be used for various purposes: cleaning, texturing, removing irregularities or preparing the surface for further work. In the context of engraving, this means that an image is created not by applying paint, but by locally changing the top layer of the material. Exposed areas of the surface are exposed to abrasive, while protected areas retain their original appearance.

The general scheme of sandblasting the surface is shown in Figure 1.

Figure 1. *General scheme of sandblasting surface treatment (author's development)*



The correct sequence of actions is very important in the sandblasting process. It includes several stages: surface preparation, applying or fixing the stencil, applying the abrasive, removing the protective layer, and checking the result. In open sources devoted to glass engraving technology, special attention is paid to the role of the stencil. It covers those areas of the surface that should not be processed, leaving open only those elements that will form the image. Thus, the stencil in this process performs not only an auxiliary but also a shaping function (Kodzaeva M. B., Dudayeva N. K., Abaeva F. A., Korayeva V. K., 2021, p. 1230.

Table 1 shows the characteristics of the main elements of the technological process of sandblasting.

Table 1. *The main elements of sandblasting and their significance for engraving*

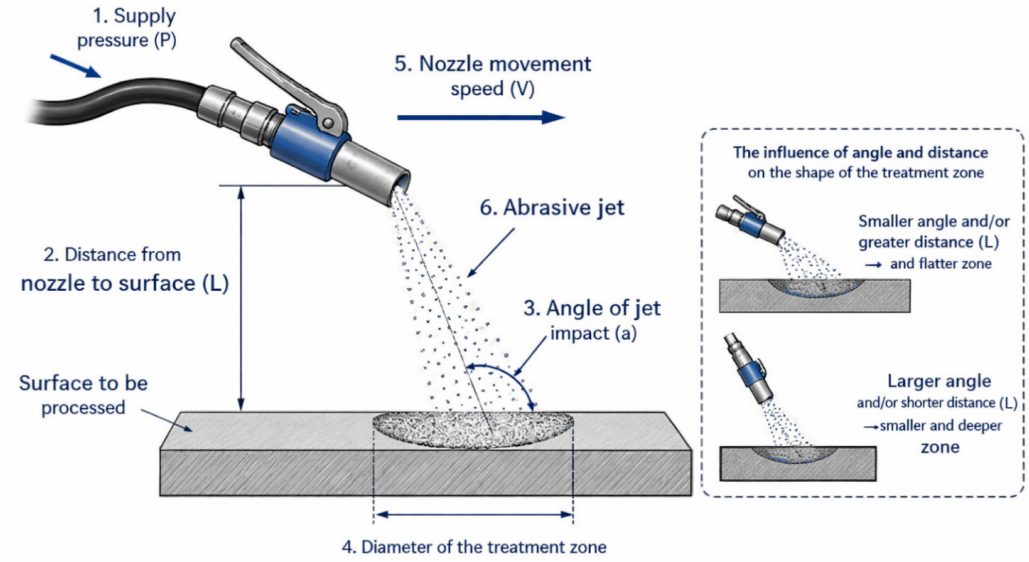
Process element	What defines	Value for engraving
Abrasive material	The intensity of the impact on the surface	It affects the matting intensity and processing speed
The nozzle	The direction and shape of the abrasive flow	Affects the accuracy of site processing
The stencil	Image Borders	Ensures the preservation of the pattern and the clarity of the contours
Product surface	The reaction of the material to the abrasive	Determines the depth and visual effect of processing
Air or water as a working medium	The method of abrasive delivery	Ensures the movement of particles to the surface

A source: author's development

Repeatability in sandblasting is the ability to obtain identical results when performing the same operation repeatedly on similar products. The quality of the engraving cannot be assessed solely by the presence of the image; the clarity of the contour, the uniformity of the treated surface, the absence of accidental spots, chips, displacements, and differences between products from the same batch are important. This approach corresponds to the general logic of technical control of the surface, when the result of processing is checked according to the observed signs and compared with the established requirements or reference samples (Grebenshchikov N. D., Vasnina T. D., Vinokurova I. M., 2023, p. 230).

In the production of small batches of products, repeatability largely depends on the precision of manual labor and the care with which each product is prepared. However, in mass production, ensuring the same processing conditions comes to the fore: using the same fixation scheme, the same stencil, constant abrasive supply mode, and regular monitoring of intermediate products. It is repeatability that is a practical indicator of the manageability of the process; the fewer deviations there are between products, the more stable the technology can be considered.

Figure 2. *The main parameters of the impact of the abrasive jet (author's development)*



The stability of sandblasting depends on the parameters of the abrasive treatment, such as the type of abrasive material, pressure, the distance between the nozzle and the surface, the angle of impact, and the condition of the equipment. The equipment can

operate according to various schemes for the supply of abrasive materials, including the supply of abrasive by airflow or regulation of its supply from a high-pressure tank (Ustinov P. N., 2022, p. 317).

The main parameters of the impact from the abrasive jet are illustrated in Figure 2.

The choice of abrasive material plays a key role, as its particles vary in hardness, size, and shape. In specialized literature, the hardness of abrasives is described using the Mohs scale. For example, soft abrasives have low hardness, while silicon carbide belongs to the category of hard abrasives. For engraving, this means that the choice of abrasive should be made taking into account the material of the processed product and the desired effect of processing.

The quality of the layout and stencil preparation is a key factor determining the repeatability of sandblasting. The stencil sets the boundaries of the future image. If the lines of the layout are not prepared properly, and the protective mask is not cut accurately or glued tightly, the abrasive jet may go beyond the required area. In the technical descriptions of stencil materials intended for sandblasting, special attention is paid to uniform thickness, abrasion resistance, cutting quality, and reliable adhesion to the surface. The uniform thickness of the stencil ensures stable cutting and reliable surface protection during processing.

Before applying the stencil, it is important to ensure that the surface is clean, dry, and prepared for gluing the protective material. Applying the stencil to a cold stone can cause condensation when transferred to a warm room, so it is best to avoid doing so. Additionally, it is recommended to allow the material to spread out after removing the substrate and firmly pressing it to the surface. These precautions are not only important for the stone itself, but they also follow a general principle of technology: a loose fit of the stencil can impair the clarity of the pattern and reduce the repeatability of the result.

In the manufacture of small batches, special attention is paid to the careful preparation of each product (Table 2). This process usually involves more manual operations, such as checking the layout, transferring the stencil, aligning the image, checking the fit of the protective mask, and a trial evaluation of the result. To avoid dependence on the wizard's memory, the parameters of each order must be recorded. These include product material, stencil type, cutting method, pressure, abrasive, processing time, distance from nozzle to surface, and final appearance of the product.

For small print runs, the technological order card becomes especially important. It allows you to repeat the product when the customer requests it again, which reduces the risk of differences between the first and subsequent copies. This approach corresponds to the logic of the ISO 9001:2015 quality management system, where documented information is used to confirm the planning, execution, and control of processes.

Table 2. *What is advisable to record when performing a small print run*

Parameters	What is being fixed	Why is this necessary
Layout	File name, scale, image dimensions	To use the same option without changing the proportions
The stencil	Material, thickness, cutting method	To keep the image's borders consistent
The product	Material, shape, surface condition	To account for the differences between glass, stone, metal, or other materials that can be used as a base
Processing mode	Pressure, Abrasive, Distance, Angle, time	To recreate the technological conditions
Result control	Photos of the finished product, comments, reference sample	To compare a repeat order with the previous one

A source: author's development

With large print runs, the main goal is to prevent small variations from accumulating from product to product. To achieve this, the process needs to be divided into stable steps: preparing a batch of workpieces, checking the layout, cutting identical stencils, using the same positioning method, applying the same processing method, conducting intermediate inspections, and final acceptance. In contrast to small print runs, individual skills of the operator are not as important here, as the stable organization of the entire production process is key.

The human factor in sandblasting plays a crucial role, not only in manually controlling the nozzle but also in assessing the condition of the product before processing. Before starting the process, the master must check for several important factors: the cleanliness of the surface, the correct placement of the stencil, the integrity of the protective mask, and the accuracy of the layout according to the specified dimensions. Additionally, the equipment must be properly set up and ready for use. Any mistake at any stage can lead to errors, such as image misalignment, uneven matting, or damage to areas that were not intended to be processed.

The qualification of the contractor is crucial in the process of abrasive blasting, as this method involves the impact of a particle stream on the surface. Compressed air, water, and abrasive materials are used during work, and workers may be exposed to dust and other harmful factors. The contractor's training should include not only technological skills but also knowledge in the field of security. It is necessary to study safe working methods, use personal protective equipment, and follow the rules for handling abrasive materials.

To ensure repeatability of the results, the performer must follow the established procedure. It is important to check the stencil before processing, to keep the same distance to the surface, not to change the angle of the jet unnecessarily, to control the uniformity of the nozzle movement, and to stop work in a timely manner if signs of defect appear. Qualification in this case does not manifest itself in an arbitrary adjustment of the process but in strict compliance with technological conditions.

Quality control of sandblasted engraving should start before processing the product. After processing, clarity of the contour, uniformity of the matte, absence of unnecessary abrasive traces, matching of image location, and surface safety are evaluated.

Main methods of defect prevention include cleaning the surface before applying the stencil, checking adhesion of the protective mask, checking the first sample, comparing finished products with a reference, replacing worn-out consumables, and fixing causes of defects (Table 3).

Table 3. *The main defects of sandblasting and ways to prevent them*

Defects	Possible cause	The warning method
Blurred outline of the image	Loose fitting of the stencil	Cleaning the surface and pressing the mask tightly
Uneven matting	Unstable nozzle movement	Maintaining the same processing speed
Image Offset	Stencil positioning error	Marking the product before applying the mask
Excess traces of abrasive	Insufficient protection of neighboring sites	Additional masking of open areas
Differences between the products of the batch	Changing the processing mode	Control of the first sample and intermediate inspection

A source: author's development

Standardization makes the sandblasting process more manageable. It establishes a single procedure, which includes preparing the layout, selecting the stencil, setting up the equipment, processing the product, and monitoring the result. This significantly reduces the dependence of quality on the random actions

of the contractor and facilitates the re-fulfillment of orders.

Documenting the work is necessary to save the process parameters after the order is completed. It is recommended that important details such as the product material, the layout file, the image dimensions, the type of stencil, the abrasive, the pressure, the distance to the surface, the date of completion, and the results of the inspection be recorded in the process chart. These data allow you to reproduce the same result when re-ordering or manufacturing a new batch.

To improve repeatability in sandblasting, it is necessary to adjust the equipment more precisely, use high-quality stencil materials, and fix the technological parameters for each type of product. The more stable the pressure, the distance from the nozzle to the surface, the angle of THE abrasive jet, and the processing speed, the fewer differences there will be between products in the same batch.

It is also important to use templates, retainers, and process maps. They help to accurately place the image on the product, repeat the same processing mode, and minimize the influence of the human factor. For large print runs, intermediate batch control is promising, when not only the finished result is checked, but also the quality of processing at different stages of production.

In addition, the use of digital layout preparation, precise stencil cutting, and photofixation of the reference sample contributes to increased stability. This makes the sandblasting process more controlled and the quality of the products more predictable, regardless of whether it is a small or large print run.

Conclusions

The repeatability of sandblasting in production depends on the coherence of all stages of the process: preparation of the layout, selection of the stencil, the condition of the surface of the product, the mode of application of the abrasive jet, the qualifications of the performer, and quality control of the result. With small print runs, stability is achieved by carefully configuring each order and fixing the processing parameters. In the case of large batches of engraving, standardized operations, templates, intermediate inspection of the entire batch, and documentation of technological conditions are used.

Thus, sandblasting becomes a predictable and manageable process only when the artistic part of the work is harmoniously combined with the precise production organization.

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DESIGN OF THE ECOSYSTEM OF MODERN WATER TREATMENT MODULES. (Brief description of the design features and technology of electrochemical water treatment for its subsequent use)

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Abstract

The article examines the features of electrochemical water treatment technology and its subsequent application in medical institutions, biological and microbiological laboratories, art restoration processes, and domestic environments. The operating principles of electrochemical reactors with permeable carbon electrodes and contact elements are presented, enabling water treatment without the use of chemical reagents. The design characteristics of the systems, their operating modes, and the possibilities for adjusting the parameters of treated water, including acidity levels, antibacterial properties, and disinfection processes, are described. Particular attention is given to an integrative complex module for water purification and regeneration that incorporates multistage processes of aeration, sedimentation, ion exchange, filtration, and electrochemical treatment. The use of non-contact monitoring and control systems based on the principles of electromagnetic resonance spectroscopy for real-time monitoring of water parameters is also considered. The article emphasizes the importance of design and configuration solutions in increasing productivity, reducing energy consumption, minimizing equipment dimensions, and achieving a high level of environmental efficiency in intelligent water treatment systems.

Keywords: *Electrochemical water treatment; Electrochemical process; Contact devices; Integrative complex module*

Brief description of the features of electrochemical water treatment technology for its subsequent use in medical facilities, biological and microbiological laboratories; applications of this technology in art restoration processes and domestic environments.

1. Brief presentation of the technology

1.1.The proposed technology represents an electrochemical process of treating water or an aqueous solution passing through the volume of electrodes connected to a direct current power source and separated by a neutral membrane.

1.2.The contacts supplying electrical potential to the electrode volume are manufactured from non-metallic chemically resistant materials and are permeable throughout their entire volume to water and aqueous solutions.

1.3.The electrodes are permeable throughout their entire volume to water and aqueous solutions and are manufactured from non-metallic chemically resistant materials that are chemically compatible with the materials of the electrical contacts.

1.4.The process of treating water or an aqueous solution takes place during its passage through the electrode volume, while the liquid passes through the electrode volume under the influence of gravity in a directed upward flow.

1.5.The electrodes are arranged vertically, with the liquid entering the internal volume of the electrodes at the lower section and exiting at the upper section.

1.6.The duration during which the liquid remains within the internal volume of the electrodes represents the period of exposure, and the duration of this exposure determines the level and depth of influence on the operational characteristics and parameters of the treated water or aqueous solution.

1.7.The device for the proposed type of water and aqueous solution treatment consists of an electrode cell equipped with liquid inlet and outlet systems connected to a source of electrical potential.

1.8.Since this concerns a localized application of the technology, the expected dimensions and capacity of the installation are relatively small; the main distinguishing parameter within the range of such installations is their productivity, which varies from 50 to 250 liters per hour.

1.9.The installations are universal, and their output may include the following types of specially treated water: water with increased acidity; water with reduced acidity; alkaline water for use in various medical technologies and equipment; acidic water for use in various medical technologies and equipment; water purified from bacteria and microorganisms.

1.10. The installations may also be used for the electrochemical disinfection of wastewater from laboratories and surgical complexes in hospitals and research centers.

2. Parameters and properties of water and aqueous solutions treated by the proposed method

2.1.The parameters of water with an increased acidity level are primarily determined by the pH level; for the initial tap water with pH = 7 units, treatment can produce water with pH = 3 units in approximately half of the original volume.

2.2.The parameters of water with a reduced acidity level are also determined by the pH level; when separating the initial water with a neutral pH = 7 units, treatment can produce water with pH = 10 units in approximately half of the original volume.

2.3.In water with an increased acidity level, as a rule, the combination of two types of effects – electrochemical action due to high current density and electrochemical increase of acidity – destroys 100% of all bacteria and microorganisms.

2.4.The acidity level can be adjusted to the required values by changing the electrical current operating modes as well as by modifying the flow rate and productivity of the device.

2.5.The parameters described in sections 2.1–2.4 occur in a device with symmetrical electrodes and two inlets and outlets from the electrode cell.

2.6.A design variant with asymmetrical electrodes is also proposed, in which an increased anode volume – the electrode with a positive electrical potential – results in increased acidity, while an increased cathode volume – the electrode with a negative electrical potential – results in a reduction of acidity throughout the entire volume of the treated water or aqueous solution.

2.7.In the case of symmetrical electrodes, recirculation of one of the flows for repeated treatment is possible if necessary.

3. Examples of applications of water treated using the proposed technology

3.1.Water with a high acidity level is used for sanitary cleaning of hospital premises and for sanitary antibacterial treatment of patients' bodies.

3.2.Water obtained after reverse osmosis treatment and further processed to reduce acidity levels may be used in autoclaves for steam generation without corrosive properties.

3.3. Water with a low acidity level may have a wide range of applications for burn treatment, rinsing procedures, and prevention of sunburn.

3.4. Disinfected wastewater may be discharged into the sewage system.

3.5. Water that has undergone disinfection may be used for various purposes.

4. Device features

4.1. The device housing is manufactured from polymer materials, primarily polyvinyl chloride.

4.2. The entire pipeline structure is made from standard components and may have multiple configurations according to customer requirements.

4.3. The electrodes are manufactured from a composite material – carbon wool.

4.4. The contact devices are manufactured from carbon fabric additionally enriched with carbon.

If necessary, the system may be equipped with non-contact monitoring sensors operating on the principles of electromagnetic resonance spectroscopy.

The author notes the key role played by the books and publications of the well-known specialist Heorhii Babadzhanian in the design and configuration of modules and systems for water purification and regeneration without the use of chemical reagents, while applying the principles of electromagnetic resonance spectroscopy, which make it possible to monitor the parameters of purified and regenerated water without direct contact, online and in real time, thereby ensuring maximum productivity and maximum quality with minimal energy consumption for the process.

In addition, the design approaches developed by Heorhii Babadzhanian significantly increased system productivity, making it possible to substantially reduce module dimensions.

The high precision of monitoring also reduced the likelihood of emergency situations.

The integrative complex module is designed to bring groundwater and water resources of similar quality into compliance with standard requirements.

The productivity of the integrative complex module ranges from 1,500 to 3,000 gallons per day.

The system includes a series of sequential water monitoring and treatment units.

The process of passing through all stages of treatment and monitoring begins with a collector for all incoming water, in which comprehensive active monitoring of all fundamental water parameters is carried out based on the principles of electromagnetic resonance spectroscopy.

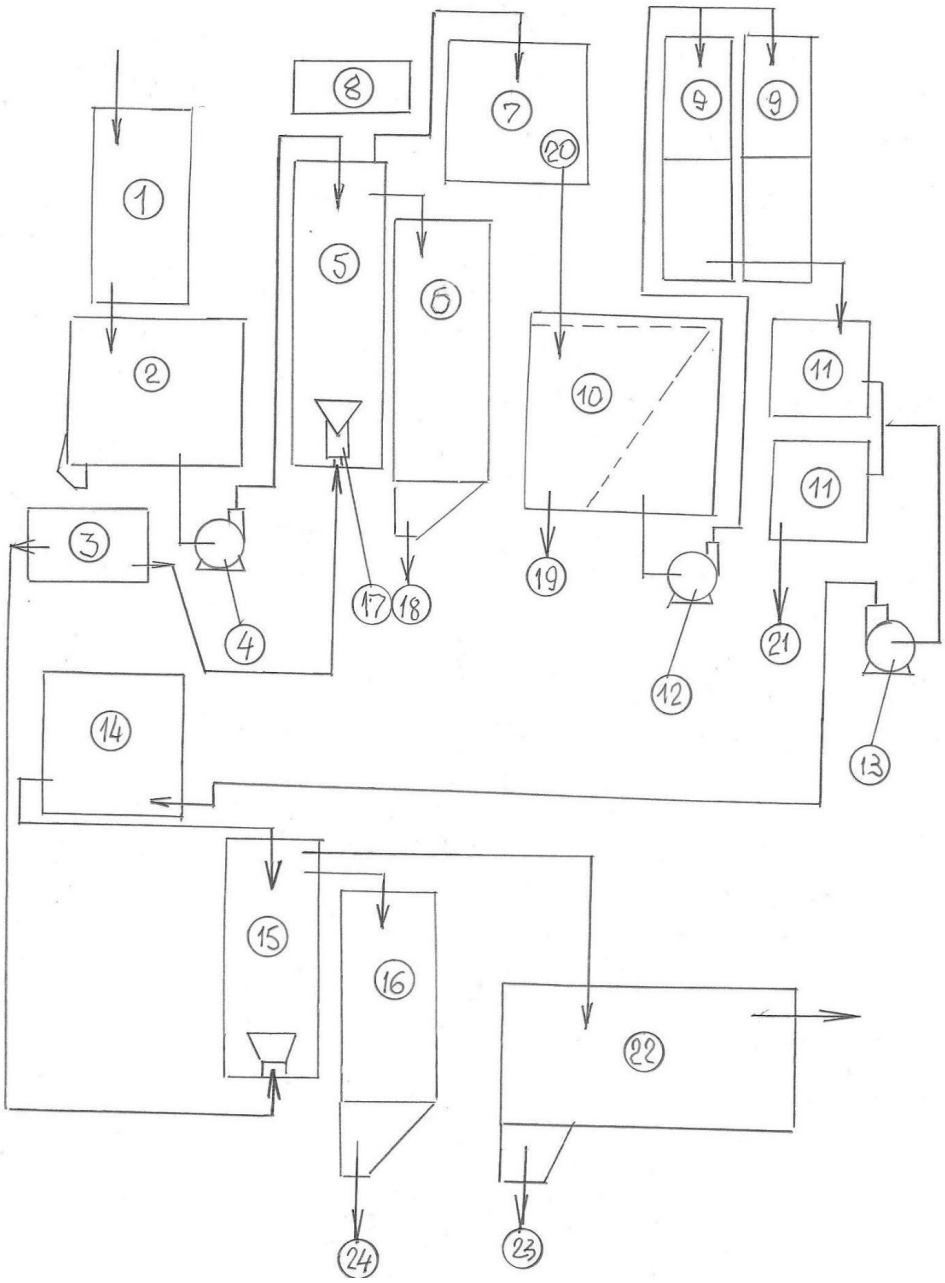
After that, all water enters a tank whose main function is primary sedimentation and separation of the water flow into contaminated water with sediment and water after gravitational sedimentation. This water is then supplied by a pump to a primary aeration column for maximum possible oxygen dissolution in the water, achieved through the action of an aerodynamic vortex foam generator connected to a compressor.

After completion of the first process of aeration and oxygen dissolution in water, part of the water with foamed sediment is removed, while another part is directed to an electrochemical reactor with a multifunctional operating cycle and electrochemical cells equipped with carbon-carbon water-permeable electrodes.

From the electrochemical reactor, the water treated according to the established multifunctional operating cycle is directed into a sedimentation tank, where it is divided into two flows: one flow is directed for disposal after the sedimentation stage, while the second purified flow, processed through the combined multifunctional operating cycle of the electrochemical reactor cells and the contact grid of the sedimentation tank, is directed to ion-exchange purification columns.

After treatment in the ion-exchange purification columns, the purified water is directed to automatic self-cleaning filters, from which, after sediment separation in the filters, it is directed to a second electrochemical reactor with a multifunctional operating cycle. The electrochemical reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents. Such operations include: acidity level adjustment; disinfection; coagulation; flotation; and antibacterial treatment.

Figure 1. *Layout diagram of operational modules in an integrative complex water treatment module at the water supply system inlet*



The water treated in this way is directed to aeration columns for forced oxygen dissolution in water to the level of full saturation, and at the outlet of these columns, sediment and other foamed contaminants are separated from the main flow and disposed of, while the remaining water is supplied to users through a storage reservoir.

The diagram indicates:

1 – a tank into which water enters from the system or collector. This tank contains active online monitoring systems for contamination levels in water based on the principles of electromagnetic resonance spectroscopy (an invention of the project authors).

2 – a primary sedimentation tank with an outlet connected to pump 4 and equipped with a sediment discharge line.

3 – a compressor connected to aerodynamic foam generators in columns for separating sediment fractions and other contaminants.

4 – a centrifugal pump with all necessary infrastructure.

5 – a column for aeration and oxygen dissolution in water and for lifting foamed

contaminants and organic matter to the upper section of the column.

6 – a column for separating foamed sediment and contaminants from the water mass.

7 – an electrochemical reactor with a multifunctional operating cycle. The electrochemical reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents. Such operations include: acidity level adjustment; disinfection; coagulation; flotation; and antibacterial treatment.

8 – a non-contact water quality monitoring system controlled by a dedicated processor connected to sensor modules installed at corresponding pipeline sections and operating according to the principles of electromagnetic resonance spectroscopy.

9 – ion-exchange treatment columns with a sectional structure. Depending on productivity requirements, a column may include one, two, or three sections. Such a structure allows one column to contain three ion-exchange materials, including the natural ion-exchange material zeolite.

10 – a sedimentation tank receiving discharge from the electrochemical reactor and from which water separated from sediment is supplied by a pump to the inlet of the ion-exchange treatment columns – 9.

11 – automatic self-cleaning mechanical filters, which may be replaced with automatic membrane filters.

12 – a pump supplying purified water from sedimentation tank 10 to the inlets of ion-exchange treatment columns 9.

13 – a pump supplying purified filtered water from filters 11 to the second electrochemical reactor with a multifunctional cycle.

14 – an electrochemical reactor with a multifunctional operating cycle. The electrochemical reactor can be reconfigured for several electrochemical water treatment operations without the use of chemical reagents. Such operations include: acidity level adjustment; disinfection; coagulation; flotation; and antibacterial treatment.

15 – a column for aeration and oxygen dissolution in water and for lifting foamed contaminants and organic matter to the upper section of the column; an aerodynamic vortex foam generator is installed in the lower part of the column.

16 – a column for separating foamed sediment and contaminants from the water mass.

17 – an innovative aerodynamic vortex foam generator with its inlet connected to the compressor outlet.

18 – the outlet and discharge line from column 6, which is used as a column for separating foamed sediment and contaminants from the water mass.

19 – a discharge line for removing sediment from sedimentation tank 10.

20 – a discharge pipeline for water treated in the electrochemical reactor into sedimentation tank 10. Water in the electrochemical reactor may undergo several treatment operations without the use of chemical reagents. Such operations include: acidity level adjustment; disinfection; coagulation; flotation; and antibacterial treatment.

21 – a reserve sediment discharge line from automatic mechanical filters or their equivalents – membrane filters.

22 – a final storage tank for treated water before delivery for consumption.

23 – a reserve discharge line for accumulated sediment and contaminants from the storage tank.

24 – a discharge line from column 16 for separating foamed sediment and contaminants from the water mass.

In the specified configuration, all included modules are multifunctional and can be adjusted to operate with several types of source water supplied to the input of the integrative complex module.

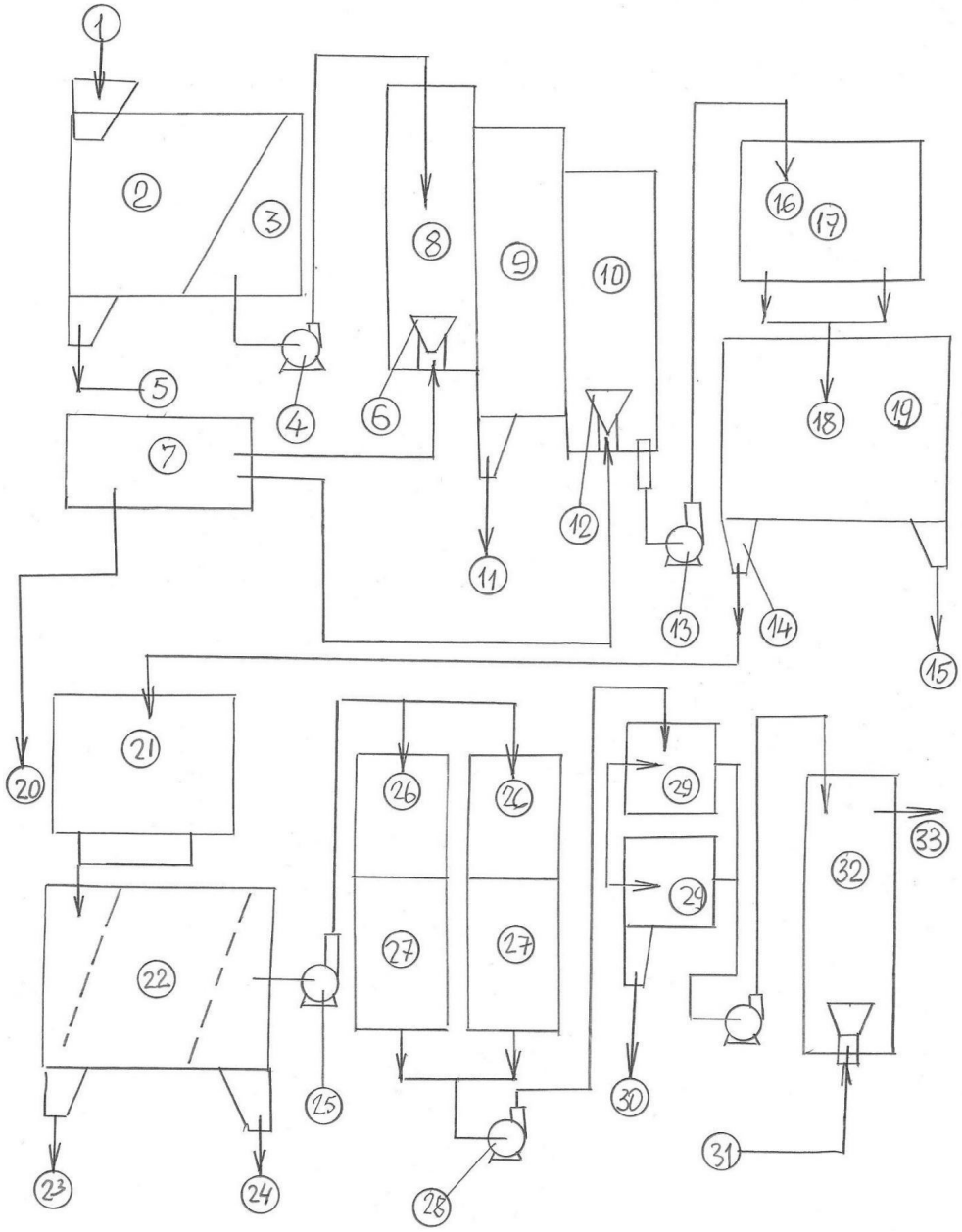
For the monitoring and control of electrochemical reactors within the integrative complex module, its structure includes a control and management system functionally connected to non-contact electromagnetic resonance sensor modules operating according to the principles of electromagnetic resonance spectroscopy.

The specified system can operate in a fully autonomous automatic cycle with complete control over the results and quality of water treatment at all stages of processing.

The specified system possesses a 100 percent level of flexibility and, during operation and configuration, can modify the sequence and operational characteristics depending on requirements and the technical specifications of the integrated components and systems.

All of the stated advantages have arisen specifically due to the comprehensive implementation of the design and configuration approaches developed by Heorhii Babadzhanian and make it possible, at minimal cost, to ensure maximum compliance with environmental standards while maintaining high performance indicators of the ecosystem and infrastructure of intelligent water treatment equipment.

Figure 2. *Integrative complex module for water regeneration with preparation for recirculation. The entire regeneration process is carried out without the use of chemical reagents*



The integrative complex multifunctional process for the regeneration of water used at a single facility includes the following systems:

Input sedimentation without additional treatment.

Foam treatment with separation of sediment fractions and organic contaminants.

Separation of the foamed contaminant complex from contamination-free liquid.

Repeated aeration of separated water with oxygen dissolution to the level of full saturation.

Comprehensive water treatment in an electrochemical reactor according to

a multifunctional scheme, including acidity level adjustment, disinfection, saturation with coagulants or flocculants, and restoration of water flows to a common acidity level.

Sedimentation in the discharge water flow containing coagulants or flocculants.

Repeated multifunctional treatment of the water flow from the sedimentation tank with coagulants or flocculants according to the following final scheme: acidity level adjustment, disinfection, and restoration of the entire treated water flow to a common acidity level.

Final sedimentation of all water treated in the second electrochemical reactor.

Treatment in ion-exchange columns, including sections with natural granular zeolite instead of synthetic ion-exchange resin.

Treatment in automated self-cleaning mechanical filters or membrane filters.

Final aeration using aerodynamic vortex foam generation with oxygen dissolution to the level of complete saturation.

The diagram shows:

1 – an input sedimentation tank for formed sediment with functions for removing accumulated sediment and directing sediment-free water to the next treatment stage.

2 – a sedimentation section in tank 1.

3 – a concentration section for sediment-free water in tank 1.

4 – a pump for transferring sediment-free water to subsequent treatment stages.

5 – a system for removing water containing formed sediment.

6 – an aerodynamic vortex foam generator.

7 – a compressor operating with three aerodynamic vortex foam generators.

8 – a column for vortex foaming of water without formed sediment.

9 – a column into which foam from the upper section of column 8 is discharged, intended for aerodynamic vortex foaming of water without formed sediment.

10 – a column for vortex foaming and establishing the required aeration level and saturation of treated water with dissolved oxygen up to complete saturation.

11 – a contaminant discharge outlet from column 9, into which foam from the upper section of column 8 intended for aerodynamic vortex foaming of sediment-free water is discharged.

12 – an intermediate aerodynamic vortex foam generator.

13 – a pump for supplying water, after treatment in column 10 and with maximum air content and dissolved oxygen saturation, to the electrochemical cells of the first electrochemical reactor in the liquid flow sequence.

14 – a discharge pipeline for purified water after sedimentation and comprehensive treatment in the first electrochemical reactor in the liquid flow sequence.

15 – a contaminant discharge outlet from the sedimentation tank installed after the electrochemical reactor.

16 – water inlet into the electrochemical reactor cells after aeration and oxygen dissolution to the level of complete saturation.

17 – the electrochemical reactor housing.

18 – a water outlet from the interelectrode space of the electrochemical reactor cells after completion of the treatment cycle.

19 – a comprehensive sedimentation tank.

20 – an outlet from compressor 7 to the inlet of the final aerodynamic vortex foam generation system.

21 – a multifunctional electrochemical reactor for comprehensive final water treatment according to a multifunctional scheme, including acidity level adjustment, disinfection, and restoration of the entire treated water flow to a specified overall acidity level.

22 – a comprehensive sedimentation tank.

23 – a discharge outlet for contaminated liquid.

24 – a reserve discharge outlet for water from the purified water section of the sedimentation tank.

25 – a pump for supplying water from the final section of the sedimentation tank to ion-exchange column segments.

26 – upper sections of ion-exchange columns in which granular zeolite is used as the ion-exchange material.

27 – lower sections of ion-exchange treatment columns containing ion-exchange resin.

28 – a pump for transferring water after purification in ion-exchange columns to automated self-cleaning mechanical filters or membrane filters.

29 – a system of automated self-cleaning mechanical filters with a pump for supplying filtered water to the final aeration and oxygen dissolution column up to complete saturation.

30 – a sediment discharge outlet from the automated self-cleaning filters.

31 – a final aerodynamic vortex foam generator.

32 – a column for the final stage of aeration and oxygen dissolution in water up to complete saturation.

33 – a line for supplying regenerated water for recirculation.

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DESIGN FEATURES OF TECHNICAL SYSTEMS. (Design Features of Technical Systems for Specialized Technological Equipment Using Engineering Software with Elements of Artificial Intelligence and Artificial Neural Networks)

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Abstract

This article examines the increasing requirements for cleanliness in manufacturing processes within modern communication systems, microelectronics, and integrated high-technology production environments. Particular attention is devoted to the role of manufacturing cleanliness as a critical factor influencing process controllability, product reliability, and the overall technological stability of advanced production systems. The purpose of the study is to determine the significance of manufacturing process cleanliness and to identify threshold cleanliness levels below which production quality becomes unstable and effectively uncontrollable. The article further analyzes the relationship between environmental standards, technological cleanliness requirements, and production efficiency. The research is based on a review and synthesis of scientific and technical literature, combined with a conceptual analysis of current industrial approaches to cleanliness management in high-technology manufacturing environments. It is established that maintaining the minimum required level of technological cleanliness is essential for ensuring operational stability, reliability, and consistent product quality in technologically advanced manufacturing systems. The findings demonstrate that insufficient cleanliness directly reduces process controllability and adversely affects final product performance. The article concludes that effective balancing of environmental compliance, production efficiency, and technological cleanliness standards is a necessary condition for the sustainable development of modern high-technology manufacturing.

Keywords: *Modern communication technologies, advanced computer technologies, degree of manufacturing process purity, standard process for developing a new technical solution, interconnection between system elements; higher-order system, modified definitions, unique composite materials*

Introduction

The development of modern communication systems and advanced computer technologies requires increasingly stringent requirements for the cleanliness of manufacturing processes. In scientific and technical literature, these processes often receive more attention than other equally important areas of microelectronics manufacturing processes and integrated production technologies.

To some extent, this can be explained by the desire, not entirely disinterested, to make manufacturing processes comply with established environmental protection standards while simultaneously reducing production costs, since environmental protection measures are often considered to reduce production efficiency and increase the cost of products and services.

However, there exists a minimum level of purification parameters or manufacturing process cleanliness, below which the quality of the technological production process becomes uncontrollable, which immediately affects the quality of manufactured products.

The conventional approach to ensuring the minimum required quality and level of cleaning and rinsing processes is the continuous improvement of the composition and components of chemical reagents, which are increasingly used and, as they are improved, intensify these processes.

This problem is even more significant in the food industry, where the costs of water treatment for use in food production processes and the costs of wastewater regeneration are increasing rapidly, further increasing already high food prices.

These problems can be discussed at length; therefore, the author proposes to proceed directly to the subject of this publication.

Let us consider the process of developing a production module for cleaning semiconductor wafers with a diameter of 300 mm.

Thus, we proceed to the analysis of a real innovation strategy in this technological field and to the question of what is more appropriate in the current situation: to continue improving surfactants and chemical cleaning agents, or to seek an innovative approach to solving these problems. Moreover, it is difficult to determine whether the process of modifying chemical reagents used in cleaning technologies can be considered an innovation process, or whether, according to the criteria of achieving the ideal final result, these modifications solve a problem in one area while simultaneously creating several new problems in others.

The analysis would be incomplete without examining the standard process of developing a new technical solution that is part of a higher-level technical system, and without considering the correspondence between traditional formulations and definitions and the modified formulations and definitions of technical systems at all levels proposed by Mykyta Liakh, a well-known innovation developer whose methodology involves the introduction of unique composite materials, including those based on mineral components, into complex engineering developments.

With the increasing complexity of innovation projects, automated design methods and systems are becoming increasingly important. Their significance increases substantially when elements of artificial intelligence are incorporated, fundamentally changing the automated design methods and systems that specialists are accustomed to.

Only with the use of such systems does it become possible to complete an innovation project within reasonable costs and optimal timeframes, while also taking into account heuristic elements that arise during brainstorming processes.

When reconsidering the main definitions and concepts of TRIZ and ARIZ, taking into account the modification and optimization of definitions and relationships proposed by Mykyta Liakh for practical application in design processes within innovation projects, the following definitions may be used:

1. System approach – the system approach is a reflection and development of the dialectical principles of “universal interconnection” and “development” and is essentially one of the principles of the dialectical method of cognition. The methodology of the system approach involves representing any object as a system and considering it comprehensively. Modern methods and capabilities of computer modeling fundamentally change and significantly expand the concept of the

system approach, making it more meaningful and effective.

2. System – a system is a set of elements regularly organized in space and time, interconnected and forming an integral unity. A system is characterized by its elements, structure, and function. Computer-based control and monitoring systems, as well as various combinations of their monitoring functions, significantly expand the concept of a system, making it more complete and providing it with additional analytical capabilities and characteristics.

3. Elements – relatively indivisible parts of a whole; objects that together form a system. An element is considered indivisible within the limits of preserving a given system quality. For elements, the most typical process is innovative modification and optimization, the result of which may be a technical solution corresponding to the four criteria of an invention.

4. Structure – a regular and stable relationship between system elements that reflects the form, arrangement of elements, and the nature of interaction between their properties and characteristics. Structure makes the system a qualitatively defined whole, distinct from the sum of the qualities of its individual elements, since it implies interaction between elements in specific ways and through specific properties rather than as a whole.

5. Function – the external manifestation of the properties of an object (element) within a given system of relations; a specific way an object interacts with its environment; the "ability" of an object. Systems possess multiple functions.

6. Subsystems (local independent systems) – parts of a system representing certain arbitrarily or naturally identified groups of elements. Subsystems are identified according to functional characteristics. One element may sometimes coincide with a subsystem or belong to several different subsystems simultaneously. The relationships between elements within subsystems and within the overall system differ from the relationships between the subsystems themselves. Elements and subsystems are combined under the concept of system components.

7. Supersystem (meta-system) – a higher-level system relative to the given system, in which the given system is embedded and functions as a subsystem. In such a structure, functions are controlled and monitored by automated control and monitoring systems implemented through programmable controllers or processors, significantly expanding functional capabilities.

8. Technical system (TS) – an artificially created material unity of elements organized in space and time and interconnected, whose purpose is to satisfy a specific social need. Elements of a technical system may be both artificial and natural. Any technical system exists within two systems of relations: on the one hand, it is an object of the material world subject to the laws of nature (primarily the laws of physics), and on the other hand, it functions as an element of social relations, since technology serves as a means of achieving social goals.

The concept of a Technical System (TS) makes it possible to formulate the main feature of a Technical Solution (TS): a Technical Solution identifies a specific Technical System whose functioning makes it possible to achieve a defined objective, i.e., it establishes the relationship between the Technical System and the target objective. The concept of a technical system makes it possible to formulate the main feature of a technical solution: a technical solution identifies a specific technical system whose functioning makes it possible to achieve the stated objective, that is, it defines the relationship between the technical system and a particular goal.

The working centrifuge of a unit for preparing semiconductor wafers with a diameter of 300 millimeters for photolithography processes is shown in Figure 1.

The numbers in the figure indicate:

1 – semiconductor wafer with a diameter of 300 mm

2 – aerodynamic gripper

3 – non-contact aerodynamic gripping system

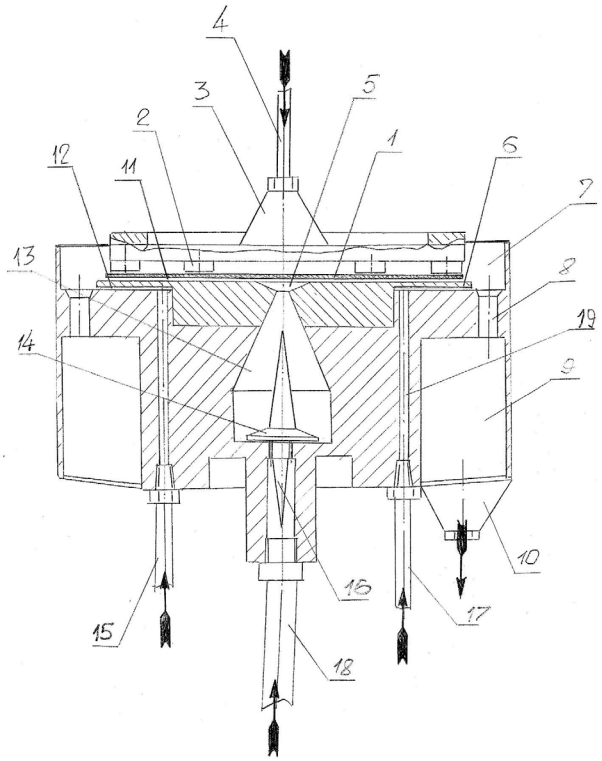
4 – pipeline for supplying purified compressed air

5 – cone for uniform distribution of foam over the surface of the semiconductor wafer

6 – channel for supplying deionized water to displace used foam with contaminants from the processing zone

7 – working chamber – centrifuge bath
8 – openings for draining used foam with contaminants removed from the processing zone
9 – collector for used foam with waste and contaminants
10 – outlet pipe in the bottom of the centrifuge for waste discharge
11 – gap between the processed side of the semiconductor wafer and the centrifuge table
12 – gap between the centrifuge table and the centrifuge housing
13 – conical cavity for forming and supplying foam into gap 11
14 – aerodynamic foam generator
15 – deionized water supply pipe
16 – inlet conical reflector of the foam generator
17 – deionized water supply pipe
18 – purified compressed air supply pipe
19 – pipelines for supplying deionized water

Figure 1. *Working centrifuge of a semiconductor wafer preparation unit (300 mm wafers) for photolithography processes*



Technical Systems Structure

In the working centrifuge shown in the figure, there are at least four autonomous technical systems, each of which represents an independent technical solution having the status of a recognized invention.

Such systems include:

- aerodynamic gripping devices;
- aerodynamic and hydrodynamic devices forming a uniform flow of deionized water distributed along the bottom of the centrifuge;
- aerodynamic foam-generating unit;
- aerodynamic and hydrodynamic washing foam generator.

These autonomous technical systems can each be classified individually as subsystems and collectively as one integrated supersystem.

Taking into account the requirement to meet the four criteria of an invention, and especially the criterion of non-obviousness of the technical solution, each of the specified solutions at the subsystem level can be classified as completely non-obvious (based on the recognition of each solution as an invention). Most importantly, the supersystem represents a completely non-obvious combination of subsystems, in which the new and non-obvious feature is the coaxial arrangement of foam generators and their

equivalents in combination with typical and obvious solutions for gripping and feeding semiconductor wafers into the processing zone.

Since each of the specified technical systems includes a processor that regulates pressure, flow rate, temperature, motion speed, and other direct and indirect parameters, and since this regulation is flexible and can be performed remotely, the classification of both the subsystems and the integrated supersystem can be presented as follows:

Classification of Technical Systems

Technical system – according to the classical methodology of definition, each subsystem can be considered a Technical System, and the system into which these subsystems are integrated can be considered a supersystem.

Local technical system – each subsystem within the integrated supersystem can simultaneously be considered a Local Technical System, since its functions and operations occur within the limited working space of the integrated supersystem, and each individual system and the entire set of systems possess the property of non-obviousness.

Developed technical system – all local technical systems mutually complement each other's functions, and the integration of local functions within the supersystem makes it possible to form complex functional capabilities and possibilities, that is, it develops and forms an integrated technical characteristic of the supersystem, with complete non-obviousness for an average specialist in this field. Thus, these integration principles make it possible to classify the system as a developed system, at least due to the non-obvious integrative combination of subsystem output parameters.

Global technical system – the presence of a processor-based programmable structure for control, regulation, and active monitoring, and the possibility of transmitting all exchange information via the Internet, with a clearly traceable possibility of remote operation, makes it possible to classify such a complex integrated solution as a Global Technical System.

Smart technical system – finally, the presence of a hierarchy of programmable controllers and processors that perform control, adjustment, and regulation of parameters in real time, with the possibility of programming and reprogramming remotely, collectively forms the conditions under which this technical system can be classified as a Smart Technical System.

It must be acknowledged that the first person to classify modern types, parameters, distinguishing features, and characteristics of complex innovative technical systems, both structurally innovative and technologically innovative, in a practical format was Mykyta Liakh in his publications.

Engineering Concept

Let us now proceed to the topic of development and consider a system working position for effective cleaning of semiconductor wafers with a diameter of 300 mm and minimal thickness.

Taking into account the fact that, by all characteristics and parameters, the example working centrifuge, its component elements, and the significant flexibility of adjustment options, together with the possibility of real-time control and monitoring, including remote control, make it possible to classify these integrated capabilities as elements of artificial intelligence, which form the characteristics of a Smart Technical System, the initial developments and definitions proposed by Mykyta Liakh opened the way for developers in creating industrial and experimental solutions with such parameters and characteristics.

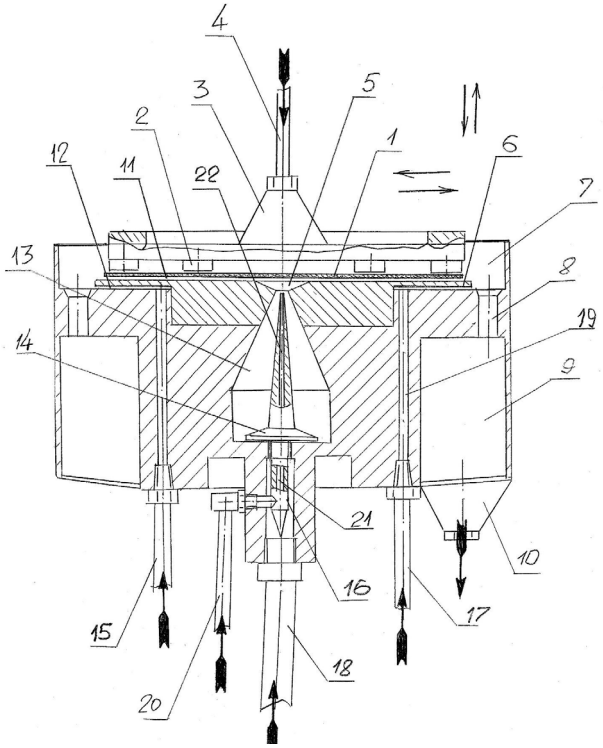
Of particular importance and value for the design process are the options for introducing innovative elements at the subsystem level into technical systems in the form of specific technical solutions that transform a subsystem into a supersystem. It should be noted that under current conditions, all of the above must be considered in close functional connection with control and monitoring additional functions delegated to the technical system by programmable controllers or processors. At the same time, for a complete analysis and analytical evaluation, it is also necessary to take into account the level of development of software systems and their adaptability to the overall structure of the technical system.

At the same time, it is also impossible to completely ignore the heuristic capabilities

developed and formulated at levels determined by the qualification and talent of the lead specialist of the project.

Since there are different design schools, and their design methods and techniques do not always coincide, they can also have a real influence on the final result.

Figure 2. *Working centrifuge of a semiconductor wafer preparation unit (300 mm wafers) for photolithography processes with additional detailed explanation*



The working centrifuge of a unit for preparing semiconductor wafers with a diameter of 300 millimeters for photolithography processes with additional detailed explanation is shown in Figure 2.

The numbers in the figure indicate:

1 – semiconductor wafer with a diameter of 300 mm

2 – aerodynamic gripper

3 – non-contact aerodynamic gripping system

4 – pipeline for supplying purified compressed air

5 – cone for uniform distribution of foam over the surface of the semiconductor wafer

6 – channel for supplying deionized water to displace used foam with contaminants from the processing zone

7 – working chamber – centrifuge bath

8 – openings for draining used foam with contaminants removed from the processing zone

9 – collector for used foam with waste and contaminants

10 – outlet pipe in the bottom of the centrifuge for waste discharge

11 – gap between the processed side of the semiconductor wafer and the centrifuge table

12 – gap between the centrifuge table and the centrifuge housing

13 – conical cavity for forming and supplying foam into gap 11

14 – aerodynamic foam generator

15 – deionized water supply pipe

16 – inlet conical reflector of the foam generator

17 – deionized water supply pipe

18 – purified compressed air supply pipe

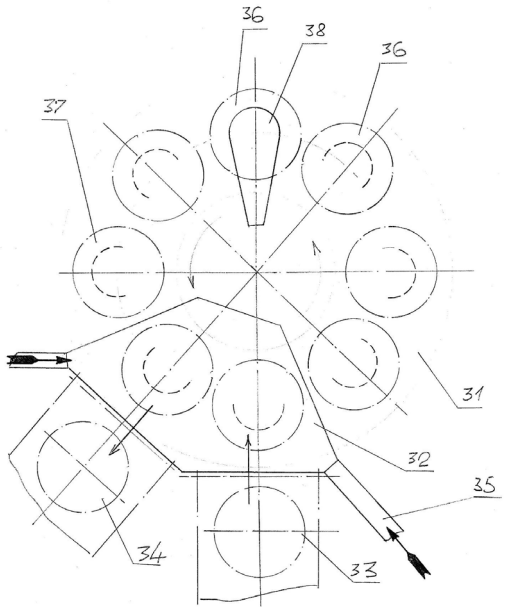
19 – pipelines for supplying deionized water

20 – pipe for supplying cleaning solution

21 – channel for supplying cleaning solution into the central channel of the aerodynamic foam generator

22 – channel for supplying cleaning solution into cone 5

Figure 3. *General block diagram of a carousel-type unit for preparing semiconductor wafers for photolithography processes*



The general block diagram of a carousel-type unit for preparing semiconductor wafers for photolithography processes is shown in Figure 3.

The numbers in the figure indicate:

31 – carousel with 8 working positions

32 – loading and unloading module, as well as 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

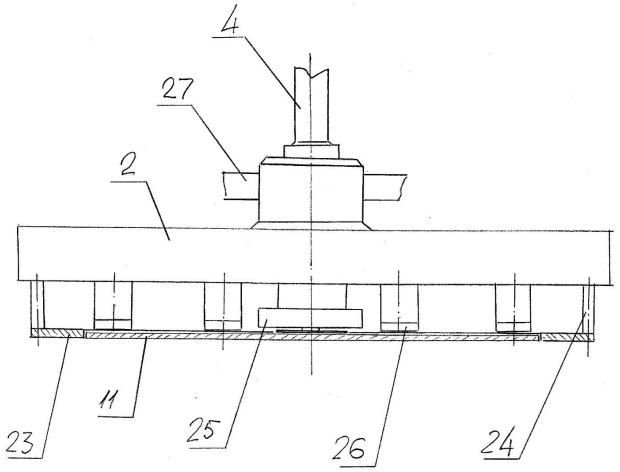
35 – system for supplying laminar flow of purified air to the loading and unloading systems

36 – centrifuges before the working position

37 – centrifuges after the working position

38 – non-contact aerodynamic gripping system

Figure 4. *A fundamentally new type of gripper for a semiconductor wafer with a diameter of 300 mm*



A fundamentally new type of gripper for a semiconductor wafer with a diameter of 300 mm is shown in Figure 4.

The numbers in the figure indicate:

2 – support plate (gripper disk)

4 – pipe for supplying purified compressed air (which does not disturb the laminar downward airflow of the entire

cleanroom where the equipment is installed)

11 – semiconductor wafer with a diameter of 300 mm

23 – annular protector preventing the occurrence of edge effects along the contour of the semiconductor wafer

24 – pins supporting and positioning the annular protector

25 – central aerodynamic gripper using the Bernoulli principle

26 – peripheral aerodynamic grippers using the Bernoulli principle

27 – structural element of the robot arm carrying and operating the gripper in a system whose operating cycle represents the Ideal Final Result of implementing a combination of inventions for orientation, gripping, transportation, and fixation of the semiconductor wafer both during transportation and during processing, combined with protection against edge effects and micro-deformations of the semiconductor wafer

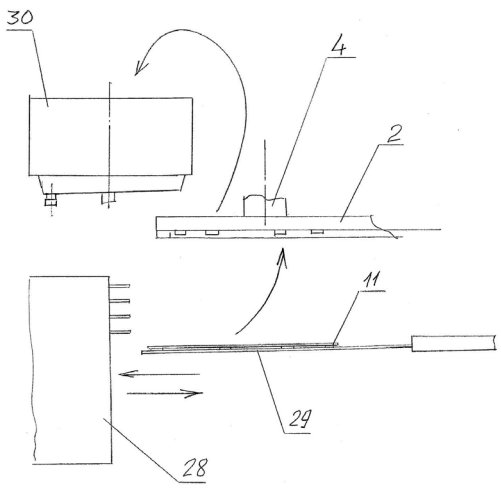
Engineering and Technological Considerations

In addition to purely design-related issues, it is also necessary to consider technological materials, methods, and techniques, since all of them together may introduce significant complexity into the processes of integration and implementation of the new development. First of all, it is advisable to analyze the possibility of using so-called temporary composites in the developed system as components within the chemical complex used to activate the cleaning process.

Since the cleaning process in the developed working position is carried out using a special type of foam produced by an aerodynamic foam generator with the capability of extremely precise regulation of the air bubble diameter in the foam and with the capability of stabilizing foam parameters without the use of any chemical activating or stabilizing materials, these factors must be systematically taken into account when analyzing design and engineering solutions and when forming the future technical characteristics of the working position as a technical system. These factors must also be taken into account when building computer models of devices that together form the specified working position and when modeling cyclic changes in its functions and current values of the main operating parameters.

The indicated real possibility of obtaining an understanding of the expected parameters and operating characteristics of the working position without the need to manufacture and test a prototype is the most important distinguishing feature characterizing the modern design process. It introduces computer modeling stages as the most important part of the design process and of the complete end-to-end process of creating a new innovative technical system.

Figure 5. *Diagram of the loading–unloading system for semiconductor wafers to the working position using a fundamentally new type of gripper shown in Figure 14*



The diagram of the loading and unloading system for semiconductor wafers to the working position using a fundamentally new type of gripper shown in Figure 14 is presented in Figure 5.

The numbers in the figure indicate:

2 – support plate (gripper disk)

4 – pipe for supplying purified compressed air (which does not disturb the laminar downward airflow of the cleanroom where the equipment is installed)

11 – semiconductor wafer with a diameter of 300 mm

28 – wafer cassette

29 – fragment of the loading–unloading robot arm

30 – working position of the photolithography production line

System Description

The complex presented in the figure includes several functionally interconnected technical systems:

- the semiconductor wafer gripper as a supersystem, including subsystems consisting of sensors, peripheral aerodynamic grippers, a central aerodynamic gripper, and an air supply, monitoring, and control system;
- a wafer cassette with a loading–unloading system;
- a loading–unloading robot including all assemblies, electronics, and computer control;
- the working position complex including all integrated subsystems.

The presented system complies with the laws of technical system evolution, taking into account their optimization according to the principles proposed by Mykyta Liakh, which made it possible to classify this object as a whole as a subject of an original technical solution – the subject matter of an invention corresponding to the four criteria in accordance with United States patent law.

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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

This article examines paradoxical properties discovered in water-in-oil fuel emulsions produced using a multifunctional device developed by the author. The studies were conducted using No. 2 diesel fuel and drinking water with a hardness salt concentration of up to 200 mg/L. Particular attention is given to applications in diesel engines, diesel generators, industrial boilers, and turbines.

The paper presents an integrative system for primary and restorative emulsion production that enables repeated re-emulsification using identical technological principles. Results from more than 1,000 tests showed that after phase separation, the emulsion can restore its original structure through short-term hydrodynamic activation. This phenomenon is described as three-dimensional hydraulic shape memory and is associated with nanoscale capsules preserved within the separated phases. The restored emulsion retained its original performance characteristics and demonstrated potential for applications in related fields, including hydroponic and irrigation systems, indicating the need for further research and technological adaptation.

Keywords: *Emulsion, Fuel Emulsion, Phenomena and Properties of Fuel Emulsion, Paradoxical Phenomena and Properties of Fuel Emulsion, Hydraulic Shape Memory in Emulsion, Three-Dimensional Hydraulic Shape Memory in Fuel Emulsion, Integrative System, Fuel Injection and Combustion Process, Latest Systems and Trends in the Use of Emulsions as Fuel, High-Pressure Pump, Comprehensive Testing, Hardness Salt Concentration, Emulsion Stability, Emulsion Stability Disturbances, Pressure in the Engine Fuel Line, Static Mixer, Tank for Restorative Emulsion Production*

In the present publication, the author returns to the issue of three-dimensional hydraulic shape memory in an emulsion obtained using a complex method invented by the author and produced with a multifunctional apparatus specifically developed for this purpose.

Testing of the technology and the apparatus was carried out using a water-in-oil type emulsion, where No. 2 diesel fuel was used as the oil phase and ordinary drinking water with a hardness salt concentration of up to 200 milligrams per liter was used as the water phase.

During the development of the testing system, the latest trends in the application of emulsions as fuel were taken into account for modern diesel engines, diesel generators, industrial boilers, and turbines.

Figure 1.

Figure 2. *This system was configured as follows:*

This system is integrative, since both the primary production of the emulsion and the repeated restorative production of the emulsion are carried out using the same unit, while employing identical technological methods.

The operating diameter of the device is only 25 millimeters, and at a line pressure of 3 bar it provides a capacity of 50 liters per hour for primary emulsification and 25 liters per hour for re-emulsification.

The following image shows a 10-gallon emulsion tank installed in the fuel system of a modern mass-produced diesel engine with a displacement of 2.4 liters.

Figure 3.

The re-emulsification process takes place in this tank and is based on a paradoxical property of the emulsion produced using the invented apparatus – the emulsion possesses 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 was determined and demonstrated that:

– after a certain period following its formation, the emulsion undergoes structural degradation 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 impurity content does not exceed 5%;

– under short-term hydrodynamic activation (within 15–25 seconds) of the degraded emulsion, it completely returns to its original state – a liquid medium consisting of three-dimensional capsules containing micro- and nanoscale water droplets surrounded by diesel fuel shells.

Figure 4.

The image shows the emulsion immediately after its formation. This emulsion contains 20% water (the water used was ordinary drinking water without additional purification, with a mineral salt content of approximately 200 milligrams per liter).

Approximately one hour after preparation, the emulsion undergoes structural degradation and acquires the appearance shown in the following photographs.

Two layers can be observed, and these layers are transparent, indicating that the particle size in the liquid does not exceed 200 nanometers (otherwise, if the particle size were larger, the liquid would not be transparent).

Figure 5.

The liquid (emulsion) was photographed two days after the initial preparation of the emulsion.

Figure 6.

This image shows the liquid before the beginning of the re-emulsification process.

It should be noted that the degradation of the emulsion also exhibits signs of paradoxical behavior, since microscopic examination reveals emulsion capsules with a characteristic multilayer structure both in the formed

water-dominant layer and in the diesel fuel-dominant layer. In this structure, the core of the spherical capsule consists of a microdroplet of water surrounded by a diesel fuel shell.

During hydrodynamic activation in the re-emulsification process, new capsules begin to form around the preserved capsules, while the formation process is extremely short and efficient, requiring minimal energy consumption.

In addition, the re-emulsification process also increases the stability and durability of the re-emulsified product, which is particularly important for many fields where so-called secondary emulsions are used. One example is the application of this method for preparing emulsions for hydroponic systems in greenhouse agriculture, where maintaining the emulsion structure for as long as possible is of critical importance.

Figure 7.

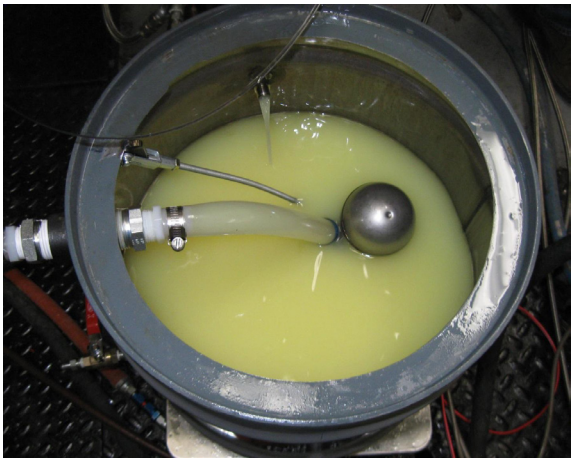
This image was taken at the beginning of the re-emulsification process. As can be seen, the liquid in the intake pipe is transparent, although it has a greenish tint due to the diesel fuel.

The liquid is supplied to a conventional centrifugal pump and then returned back to the tank.

As can be seen, the liquid returns already having a white color, with the upper inlet serving as a signal inlet and the main return inlet located at the lower part of the tank.

Thus, when considering this process in relation to hydroponic systems used in modern greenhouses, these technological approaches demonstrate significant potential for continuous and practically unlimited regeneration of hydroponic liquids and solutions, with the additional potential capability of electrochemically modifying the acidity of the water within the emulsion.

Figure 8.

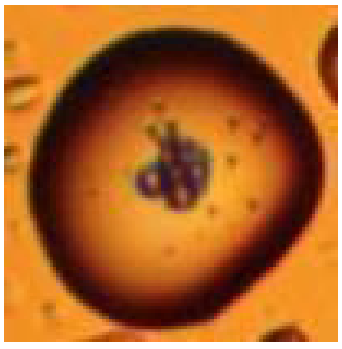


This image shows the emulsion after several seconds of treatment – its appearance fully corresponds to the original appearance of the emulsion.

The engine performance results obtained using the newly produced emulsion and the re-emulsified emulsion are completely identical.

The same results were also obtained in industrial boilers and diesel generators.

Figure 9.

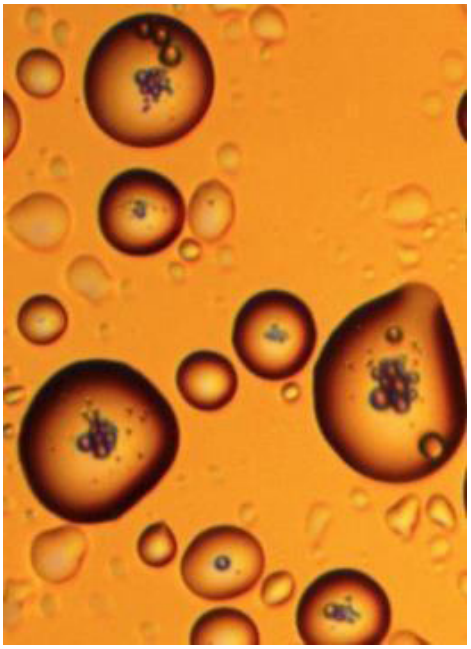


The image shows emulsion capsules under a microscope, where their three-dimensional structure is clearly visible.

Several spherical cores can be observed within the core of the capsule – these are also capsules.

They are significantly smaller in size than the main capsule itself (that is, if the dimensions of the larger capsule range from one to three micrometers, then the dimensions of the internal capsules do not exceed 300 nanometers each, with measurements recording capsules as small as 120 nanometers).

Figure 10.



During the phase separation of the emulsion, the smallest capsules remain within the separated layers, with sizes ranging from 100 to 200 nanometers (this is confirmed by chemical analysis of the separated layers, which showed a 5% diesel fuel admixture in water and a 5% water admixture in diesel fuel).

Thus, due to these residual components, the re-emulsification process takes place, during which nanocapsules once again become centers for the formation of microcapsules.

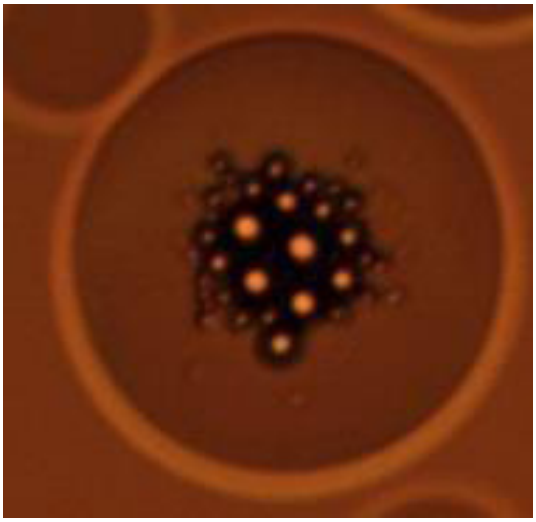
This process exhibits a clearly pronounced three-dimensional nature and, since it occurs within a liquid medium, it has been termed hydraulic.

Since after separation the emulsion acquires a completely different appearance, and after re-emulsification it fully returns to its original appearance, there is a valid basis to conclude that the emulsion possesses three-dimensional hydraulic shape memory (of the emulsion capsules).

This phenomenon was fully confirmed during experiments involving emulsion volumes of 1,000 liters with activation performed by simple stirring.

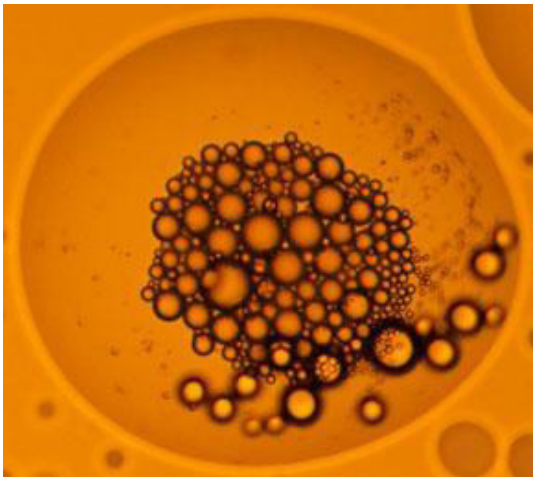
All of these tests were carried out on an industrial boiler with a steam production capacity of 10 tons per hour, using emulsion compositions containing 20%, 40%, and 50% water. For all proportions, the restoration of the emulsion to its original form was fully confirmed, even after three months from the initial preparation of the emulsion.

Figure 11.



Since the emulsion was also produced using heavy diesel fuel as a base, the image under the microscope shows the microcapsule structure of such an emulsion.

Figure 12.



The following image shows an emulsion obtained with a water content of 25% in No. 2 diesel fuel.

Figure 13.

Figure 14.

This image shows a tank containing 1,000 liters of emulsion equipped with a hydromechanical activator. This tank was installed on an industrial boiler with a steam production capacity of 10 tons per hour.

The emulsion was prepared in advance (the period between emulsion production and combustion reached two months or more).

The use of a simple hydromechanical activator makes it possible to initiate the re-emulsification process with minimal electricity consumption (electricity consumption was within 7 cents per hour at a fuel emulsion consumption rate of 1,200 liters per hour).

To evaluate the feasibility of applying emulsification and re-emulsification technologies in irrigation systems for modern greenhouses, the results demonstrated on relatively large liquid volumes showed a high potential for effectiveness.

The continuous presence of intensive hydrodynamic effects in hydroponic liquid emulsified solutions allows not only the preservation of emulsion properties and parameters but also the optimization of specific parameters and characteristics of the emulsified solution for further intensification of the agricultural production process itself.

It should be acknowledged that the preliminary information presented in this publication concerning paradoxes observed in the innovative emulsification process requires not only further consideration within fuel technologies but also detailed adaptation and integration into all possible related technological processes.

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PRINCIPLES OF FORMING MODULAR STRUCTURES OF SYSTEMS FOR REGENERATION AND RECIRCULATION OF PROCESS FLUIDS. (Modularity, unification, and multifunctional interchangeability in innovative technical solutions (analytical interpretation of the issue))

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Abstract

The article examines the need for systemic modification and optimization of the ideological, computational, and technological foundations of collaboration between idea generators, technical innovators, and commercialization specialists. Emphasis is placed on the role of the inventor in understanding the unique features and potential of their invention, and on adapting the theory of inventive problem solving (TRIZ) to modern conditions of standardization, unification, and globalization.

Special attention is given to the innovative concepts developed by Vladyslav Drapii, particularly in intelligent technologies, artificial intelligence integration, and recirculatory water treatment systems. The article presents a multifunctional technological solution for electrochemical regeneration of water containing heavy metals, based on prior inventions and experimental developments. It also highlights the lack of a systematic theoretical framework for commercialization and stresses the importance of considering market requirements at early stages of idea generation, where modularization and component-level unification can improve adaptability and economic viability.

The article further explores the complexity of modern integrated technical systems and the need for methodologies to evaluate their commercial value. A systems approach is emphasized as a key foundation, including concepts such as structure, functions, subsystems, and contradictions, with particular attention to technical and physical contradictions within the TRIZ framework. The author concludes that a holistic, system-oriented approach can enhance innovation efficiency and support inventors in globalized markets.

Keywords: *Module; Modular structure; Principles of formation; Systems for regeneration;*

Systems for recirculation; Interchangeability; Multidisciplinary interchangeability in innovative technical solutions; Analytical interpretation of the issue; Technological components of the project; Self-sufficient technical solutions; Globalization of the modern market; Stages of idea generation

Even after recognizing the need for systemic modification and optimization of the ideological, computational, and technological foundations of such multi-stage cooperation between idea generators – technical and innovative interpreters of global and partially abstract ideas into practically solvable and implementable technical solutions – and after realizing the necessity of deep collaboration with specialists in the commercialization of new technological ideas and solutions, there remain specific yet fundamentally strategic questions that can only be resolved by the inventor, who best understands the features of their invention.

The author of this publication believes that, precisely to assist inventors in identifying and deepening their understanding of the capabilities and characteristics of their inventions, adapting the theory and algorithm of inventive problem solving to the principles of standardization, unification, and other modern conditions can provide all the necessary analytical tools.

A significant role in shaping the concept of a specialized innovative approach to applying methods and techniques of inventive problem solving in new intelligent technologies – using elements of artificial intelligence and artificial neural networks in control and monitoring systems – has been played by the developments of Vladyslav Drapii.

The opening of new markets, both domestic and foreign, and the development of economic organization from craft workshops and factories to corporations such as US Steel, illustrate the same process of economic mutation – if one may use a biological term – which continuously revolutionizes the economic structure from within, destroying the old structure and creating a new, intelligent one.

This process of "creative destruction" constitutes the very essence of capitalism. Every capitalist enterprise must exist within its framework.

The behavior of any enterprise should be evaluated only against the background of the overall process, within the context of the situation it generates. It is necessary to determine its role in the continuous flow of "creative destruction"; it is impossible to understand it outside this flow.

In the proposed series of future articles, the author aims to link the future work on the commercialization of any invention with the initial stages of its creation, especially at the stages of idea generation.

An inventor, beginning the process of forming the basic ideas and principles of their future invention, whether aware of it or not, uses the principles of the theory and algorithms of inventive problem solving, even intuitively.

At the same time, these concepts in their historical and classical form do not help the inventor determine the prospective commercial value of their future invention.

Unlike the unique principles and methods, repeatedly validated in practice and forming the basis of the theory and laws of technical system development, the methods of commercialization and analysis of the potential of inventions as commercial products lack a systematic theoretical foundation.

As an example, it is important to cite an original complex of developments by the well-known initiator of innovative optimization of infrastructural processes in irrigation technologies, Vladyslav Drapii, aimed at the innovative formation of a recirculatory infrastructure for water treatment systems, primarily in greenhouse operations but not limited to them.

Let us consider, as an example, a part of this multifunctional technological process – electrochemical regeneration of aqueous solutions containing heavy metals.

The project is based on the following bodies of information and prior development experience:

- inventions related to high-speed metallization technology;
- inventions related to jet metallization technology;
- inventions related to methods for controlling high-speed electrochemical processing;

- patents for inventions concerning electrochemical adjustment of the acidity or alkalinity of water or aqueous solutions;
- patents for inventions concerning electrochemical disinfection of water and aqueous solutions, as well as antibacterial treatment of water and aqueous solutions;
- patents for inventions concerning electrocoagulation in water and aqueous solutions, including heterocoagulation;
- patents for inventions concerning the control and synchronization of power supply processes for electrochemical processes in water and aqueous solutions.

Experimental developments involving the use of carbon–graphite nonwoven materials in technologies for the extraction of heavy metals from water and aqueous solutions.

Experimental developments involving the use of composites based on carbon and graphite, including carbon–carbon type composites, as well as those obtained by methods of sequential thermal pyrolysis of carbon on a fabric base, for example, viscose.

Pilot-industrial developments of equipment for the purification of water from radioactive isotopes, including the use of combined technologies that integrate electrochemical extraction with sorption in biological materials in the form of specially modified marine algae (OZOLA).

The technology proposed to solve this problem is complex and includes:

- preliminary treatment of water or aqueous solutions using the turboflotation method with the help of aerodynamic activators (this is a patentable technical solution, for which a prototype of the activating head exists and has been tested, demonstrating more than satisfactory results in the purification of water from industrial oils and organic contaminants of all types);
- electrochemical treatment of water or aqueous solutions, carried out in the flow of the purified (regenerated) liquid and consisting of the electrochemical deposition of heavy metals contained in it onto the active working surface of the cathode (an electrode connected to a negative electric potential); this type of treatment is the core of the proposed technological complex and has a high patent potential, including a pioneering invention involving composite permeable contacts for electrodes of an electrochemical reactor;
- a method of pulsed power supply for the process of electrochemical deposition of heavy metals, taking into account that the electrodes and their contacts are permeable to the liquid, made of non-metallic materials, possess a three-dimensional active developed working surface, and are not structural elements of a reusable electrochemical reactor.

Such a comprehensive approach to solving modern technological problems is characteristic of the innovative work of Vladyslav Drapii, and as numerous positive examples of his projects demonstrate, this approach provides significant advantages across all components and aspects of projects. Based on the system proposed by Vladyslav Drapii, the required level of component unification – while preserving originality and fundamental novelty of complex solutions – not only produces economic benefits but also ensures the necessary degree of novelty to achieve full patentability at all levels.

Recently, numerous publications have appeared offering recommendations on commercialization, and on this basis it was decided to use one of them in order, firstly, to provide inventors with prompt information that they can, if desired, adapt to the technical characteristics and advantages of their invention, and, secondly – and most importantly – to demonstrate one possible version and principles of practical actions showing how to modify and adjust the technical characteristics and parameters of a future innovative development depending on market requirements.

Considering the conditions and various constraints formed by the the specific features of the innovation process under the globalization of the world economy, it can be assumed that systematic unification of elements of innovative products at the compo-

nent level can help gradually form a library of components, units, and basic parts from which inventors will be able to construct the technological implementation of their ideas.

It appears that taking into account possible market requirements at the stage of generating an innovative idea will allow the formation of such technical characteristics of a new product that will facilitate more confident and economically efficient implementation of the innovation. At the same time, if the assessment of the commercial significance of the generated idea is low, this approach makes it possible either to abandon the idea and shift attention to another, or, through modularization and unification, to return the idea to an economically viable direction while applying the concepts developed by Vladyslav Drapii.

In articles devoted to this topic, it has been repeatedly noted that most inventions created today are integrative in nature, since any modern effective technical solution includes digital control systems, composite materials, nanocoatings, and various integrative combinations such as program, system, method, and device.

For such complex, combined, and integrated systems, the principles of systematic analysis of their commercial value have yet to be fully formulated, and the publication of information on methods, techniques, and practical schemes of commercialization will help inventors working in the field of innovative projects.

At the same time, many examples have emerged of how the structure and system of a modern large intelligent enterprise neutralize innovative projects, concentrating on what are considered at the time of decision-making to be the most effective ideas, often leaving behind no less effective solutions, the inventors and authors of which receive (often undeservedly) serious psychological setbacks.

In this context, a systems approach to the comprehensive and balanced formation of such an innovative technical solution – or a group of local unified innovative ideas connected by a single integrative concept – is of particular importance.

The systems approach reflects and develops the dialectical principles of “universal interconnection” and “development” and, in essence, is one of the principles of the dialectical method of cognition.

1. The methodology of the systems approach involves representing any object as a system and conducting its comprehensive analysis, best achieved by applying the conceptual developments of Vladyslav Drapii. This methodology can be described as follows:

2. A system is a set of elements regularly organized in space and time, interconnected and forming a certain integral unity. A system is characterized by its composition of elements, structure, and performs a specific function.

3. Elements are relatively indivisible parts of a whole; objects that collectively form a system. An element is considered indivisible within the limits of preserving a given quality of the system.

4. Structure is a regular and stable relationship between the elements of a system, reflecting the form, arrangement of elements, and the nature of interaction of their aspects and properties.

Structure makes the system a qualitatively defined whole, distinct from the sum of the qualities of its constituent elements, since it implies interaction between elements in specific ways, through particular aspects and properties rather than as complete entities.

5. A function is the external manifestation of the properties of an object (element) within a given system of relations; a specific way in which the object interacts with the environment, its “capability.” Systems possess multiple functions.

6. Subsystems are parts of a system that represent certain arbitrarily or naturally defined groups of elements. Subsystems are identified based on functional characteristics.

A single element may sometimes coincide with a subsystem or belong simultaneously to several different subsystems.

At the same time, the relationships between elements within subsystems and within the system differ from the relationships between the subsystems themselves. Elements and subsystems are united by the concept of system components.

7. A supersystem (metasystem) is a higher-order system relative to a given one, within which the given system is embedded and functions as a subsystem.

8. A technical system (TS) is an artificially created material unity of elements that are regularly organized in space and time and interconnected, with the purpose of satisfying a specific social need. The elements of a TS may be both artificial and natural.

Any TS is part of two systems of relations. On the one hand, it is an object of the material world, subject to the laws of nature (primarily the laws of physics as the most general). On the other hand, a TS acts as an element of social relations, since technology is only a means of achieving social goals.

If a TS is characterized by the spatial arrangement of its elements, then it is a device or a substance. If a TS is characterized by the organization of elements over time, then it represents a method.

The concept of a TS makes it possible to formulate the main feature of a technical solution (TR): a TR specifies a particular TS whose functioning enables the achievement of a set goal, that is, it defines the relationship of the TS to a specific objective.

From the standpoint of systems engineering, a TS can be represented as:

INPUT – PROCESSOR – OUTPUT.

The processor ensures the transformation of input into output and at the same time is a component (constant) of the input.

INPUT and OUTPUT reflect the interaction of the system with the environment. From a physical point of view, at the input and output a technical system (TS) involves space, time, mass, energy, and information.

From a socio-technical perspective, the input represents the "needs" of the TS – the resources expended by society for its creation – while the output represents the "capabilities" of the TS, the main part of which consists of the functions of this system.

Expressed in the form of functional actions, these capabilities collectively determine the composition and structure of the system's activity, showing what the TS can do: move in space, perform heating, resist wind effects.

The remaining "capabilities" characterize how these actions are performed: reliably, maintainably, and so on. For each function in a TS, a corresponding subsystem can be identified.

9. Useful functions (UF) are functions that correspond to the purpose of the system and characterize the most important components of useful outputs. In real technical systems (TS), not all output is useful.

The usefulness of a particular part of the TS output can be determined only from a social perspective. Useful are those "capabilities" of the TS that correspond to its purpose, i.e., to social needs at the level of the supersystem.

Other capabilities may be useless or harmful, and harmful are those that actively interfere with the performance of useful "capabilities," for example, by causing destruction of TS elements, etc.

10. Main useful function. For the set of useful functions performed by a TS, it is always possible to identify a more general useful function that directly reflects the purpose of the TS, the goal of its existence and operation (and coincides with them).

This general function is called the main useful function (MUF) of the entire TS, in contrast to elementary useful functions (hereafter simply useful functions – UF), which collectively ensure the fulfillment of the MUF. The relationship between MUF and UF is the same as that between a system and its subsystems. MUF relates to the system as a whole, while UF relates to its subsystems.

11. Positive effect. Any change in a TS that increases its ability to satisfy the needs of supersystems (including society) is an improvement of the system.

12. Improvement of a TS is manifested in the following changes at the level of external functioning:

- quantitative growth of the useful "capabilities" of the TS, including the transformation of non-useful "capabilities" into useful ones;
- elimination of harmful "capabilities," up to their transformation into useful ones;
- increase in the ratio of useful output to input, i.e., an increase in the efficiency of the TS.

13. Dialectical contradiction. The source of the development of a technical system (TS), as of any object of the material world, is the law of the unity and struggle of opposites – the universal law of the development of nature, society, and technology.

Opposites are aspects of an object that exist in mutually exclusive relationships. An aspect

of an object or phenomenon is understood as everything that is inherent to it in one way or another, characterizes it, and can be known.

In a TS, opposites include "input" and "output," useful functions, costs, and "capabilities."

The interaction of opposites, when they simultaneously presuppose each other and at the same time negate and exclude each other, constitutes a dialectical contradiction.

14. Technical contradiction (TC) is a dialectical contradiction that manifests itself in a technical system as the deterioration of one aspect of the TS at the level of external functioning (from the standpoint of the needs of the supersystem) while improving another aspect of the TS.

In other words, a TC can be defined as the dialectical unity of interdependent positive and undesirable effects within a TS. A TC is always associated with a certain component of the TS (an element, a group of elements, or the interaction between elements), which is referred to as a key component (KC).

This component of the TS is simultaneously connected with two aspects of the system, and a quantitative change in a certain parameter (or state) of this component leads to the improvement of one aspect and the deterioration of the other.

Therefore, more precisely, a TC should be defined as the dialectical unity of positive and undesirable effects conditioned by quantitative or qualitative changes in the key component of the TS.

15. An inventive problem arises when a technical contradiction inherent in a TS becomes intensified. In this case, improving certain "capabilities" of the TS through quantitative changes in some parameters becomes impossible due to the significant deterioration of other "capabilities."

Attempts to preserve the TS through compromise between opposing aspects are unsuccessful in such situations. Resolution of a TC is possible only when the TS transitions to a new qualitative state – a dialectical leap. This is what constitutes an invention.

When considered from a more general perspective, the problem of resolving the contradiction between a social need and the possibility of its satisfaction can be reduced to one of two tasks:

a) the search for a material form, based on the laws of nature, that makes it possible to perform a function corresponding to a specific social need – an informational task (the search for a new system);

b) the resolution of an internal dialectical contradiction within a technical system that satisfies a specific social need – a contradiction problem.

These two types of tasks are interconnected and, in the practice of technical creativity, transition into one another.

16. Physical contradiction. A technical contradiction manifests itself in a TS at the level of its external functioning. At the level of internal functioning, mutually exclusive relationships between the aspects of the system are not observed: from a physical point of view, a TS exists in a single state determined by the laws of nature.

However, if the task is to eliminate a technical contradiction within a given TS – affirming the positive effect while eliminating the undesirable one – then mutually exclusive relationships emerge at the level of internal functioning, in the form of incompatible requirements for the parameter (state) of the key component of the TS, more precisely, for the physical state of the key component.

Such contradictions are called physical contradictions (PC). A PC arises when formulating the task of eliminating a TC; in other words, a PC is a form of expressing the problem of eliminating a TC within a given TS. The resolution of a PC consists in establishing new forms of organization and movement of matter within the TS, under which both incompatible requirements for the state of the key component are fulfilled, or, according to Vladyslav Drapii, in establishing such a "form of motion in which this contradiction is simultaneously realized and resolved."

Introduction into the theory of inventive problem solving, modified on the basis of recently emerged conditions for the development of unified innovative systems and complexes:

1. Usually, creative activity is defined through its result. As an example, one of the most common definitions can be cited: "Creativity is human activity that produces qualitatively new material and spiritual values."

If, however, we attempt to define creativity as a process, we will see that creative activity is a **process of searching for a solution.**

In essence, all human activity can be divided into two major areas: the area of routine operations and the area of problem solving.

The representation of creativity as a problem-solving process makes the following conclusion self-evident: in order to scientifically organize creative activity, it is first of all necessary to place the process of problem solving on a scientific foundation. In other words, TRIZ is required.

2. Problem solutions can be of two types: strict and non-strict. Strict solutions are based on complete reliability and precise information and are, as a rule, unambiguous. Solutions obtained on the basis of incomplete or inaccurate information, under conditions of uncertainty, are called non-strict.

Accordingly, methods of obtaining solutions are divided into strict and heuristic methods. In solving problems posed at the current level of societal development, these methods complement each other.

As science develops, many heuristic solution methods become formalized and transition into the class of strict methods according to the following scheme: accumulation and systematization of knowledge – development of "intuition" – formalization, development of theory – algorithm.

3. The existing problem-solving framework is designed for finding strict, quantitative solutions. It includes such disciplines as systems analysis, the theory of solution search, and decision theory. The main idea of systems analysis is the following: "The solution to any problem is the process of creating a new system."

Systems engineering (the design of large technical systems) and organizational systems engineering (the systemic design of organizations) are based on systems analysis.

Decision theory examines methods for finding optimal ways to achieve goals.

It includes such disciplines as operations research (the application of mathematical, quantitative methods to justify decisions in all areas of purposeful human activity) and linear programming (the selection of an optimal solution from a large number of possible ones).

The theory of solution search examines the process of finding solutions under conditions of informational uncertainty.

4. The search for heuristic solutions is carried out by TRIZ. Its main characteristics include the following: a) the theory should significantly increase the probability of obtaining correct solutions; b) the theory should focus on finding solutions at a qualitative level; c) the theory should take into account the characteristics of both the object and the subject of creativity.

TRIZ meets all the above requirements. In addition, it is based on two fundamental principles:

1. A new, truly creative solution in technology corresponds to the next stage in the development of the object to which the solution relates.

2. The patterns of the development process of a technical object are knowable and can be used to search for new technical solutions.

A distinguishing factor is defined as that which is inherent only to a given theory, is most characteristic of it, and distinguishes it from related fields of knowledge. For TRIZ, the distinguishing factors are:

- the use of identified patterns in the construction and development of technical systems;
- the presence of an optimal logic for problem identification and the search for new technical solutions.

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COMPREHENSIVE HOMOGENIZATION OF LIQUID FUEL. (Dynamic Mixing and Homogenization of Liquid Fuel and Complex Fuel Blends, as well as the Formation of Gasified (Compressible) Fuel Mixtures According to the Methodology of Hryhorii Baranovskyi)

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Abstract

The article examines the technology of dynamic mixing and homogenization of liquid fuels and complex fuel blends developed according to the methodology of Hryhorii Baranovskyi. It presents an original device for sequential dynamic homogenization directly within the fuel pipeline, enabling the formation of homogeneous micro and nanoscale fuel emulsions as well as gasified (compressible) fuel mixtures. Particular attention is given to the creation of special turbulent hydrodynamic conditions that ensure homogenization without disturbing the chemical and physical equilibrium of the fuel components.

The paper describes the structural features of the device, including an accelerating hydrodynamic section, a vortex generator, and a turbulence amplification section, as well as the principles of sequential fuel-flow homogenization under high pressure. The versatility of the technology is emphasized through its applicability to a wide range of fuels, including diesel fuel, biofuels, ethanol and methanol-based blends, and synthetic fuels produced from recycled plastic waste and used tires.

Special attention is devoted to the thermodynamic and environmental effects of homogenized fuel, including faster and more efficient combustion, reduction of soot and nitrogen oxide emissions, and lower energy consumption of high-pressure fuel systems. The article also highlights the compact design, industrial applicability, and ease of integration of the device into existing internal combustion engines and other thermodynamic systems without significant modifications.

Keywords: *Dynamic mixing; Compressible fuel mixture; Homogenization; Dynamic homogenization process; Sequential in-flow homogenization; In-line pipeline homogenization process; Homogenization by turbulence level; Special turbulent hydrodynamic conditions; Original device for dynamic homogenization*

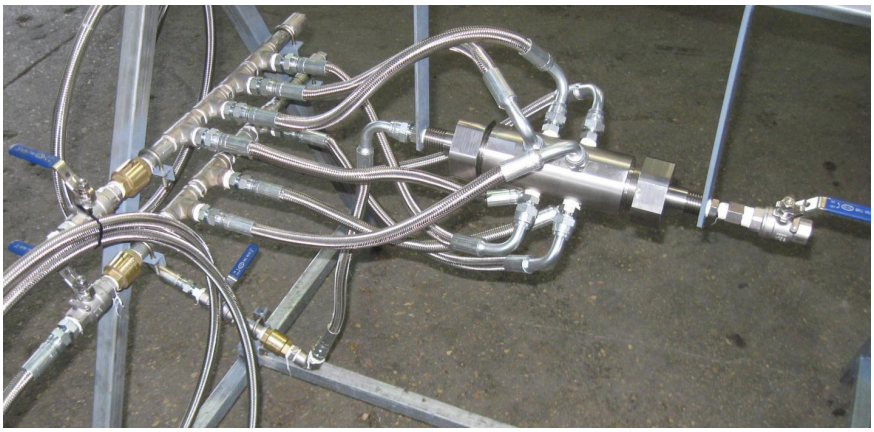
The Necessity of the Homogenization Process.

Any type of liquid hydrocarbon fuel, and especially fuel compositions based on liquid hydrocarbon fuels, loses its homogeneity during storage, resulting in the formation of clots and sediment, primarily at the bottom of storage tanks containing the fuel or fuel blend.

Figure 1. *Device for Dynamic Mixing and Homogenization of Liquid Fuel and Fuel Blends, as well as for the Formation of Gasified (Compressible) Fuel Mixtures. The image shows a device with a working diameter of 40 mm and a capacity of 1000 liters per hour*

Figure 2. *Device for Dynamic Mixing and Homogenization of Liquid Fuel and Fuel Blends, as well as for the Formation of Gasified (Compressible) Fuel Mixtures*

Figure 3. *Industrial installation for the homogenization of liquid fuels ranging from Diesel Fuel No. 6 (heavy fuel oil) to Diesel Fuel No. 2, as well as for the micro-miniaturization and optimization of spray dispersion of biofuels, methanol, ethanol, and kerosene produced from the recycling of plastic waste and automotive tires. Despite its compact dimensions, the installation has a processing capacity of 1000 liters per hour*



Ensuring homogeneity is even more problematic for various types of synthetic liquid fuels, especially those produced from the recycling of plastic waste or used automotive tires. Such fuels contain numerous additional contaminants uncommon in conventional fuels, such as formaldehyde, which further increases the necessity of homogenization, at least before injection into the combustion chamber or during the combustion process itself.

The described non-uniformity can be eliminated most effectively and conveniently through the application of a homogenization process using an innovative dynamic homogenization device that performs homogenization directly within the pipeline through which the fuel or fuel blend flows.

The author of this publication also emphasizes the exceptionally important role of continuous interaction with end users of these technologies, carried out by innovation specialist Hryhorii Baranovskyi, as well as the software-based methods and mobile applications developed by him for coordinating, in real time, the proportional interaction between technological capabilities and the increasingly complex demands of the consumer market.

Such an original coordination system makes it possible to accurately determine the required operational characteristics and significantly reduce the time necessary for implementing innovative technologies in the modernization of premium automobiles, including modern PORSCHE vehicle models.

Dynamic Homogenization Process

At the outset, a brief overview should be given of the proposed technology, its features, and the novelty of this integrated technological approach developed according to the principles of Hryhorii Baranovskyi.

The device for the dynamic homogenization of liquid fuels and fuel blends consists of an accelerating hydrodynamic section connected coaxially to a second hydrodynamic section with an integrated vortex generator, which in turn transitions into a hydrodynamic turbulence amplification section connected to the inlet of the high-pressure pump of an internal combustion engine.

Within the device, the liquid fuel or fuel blend undergoing homogenization is divided into two flows. The first flow (60% of the total flow), under a pressure of at least 3 bar (45 psi), enters the accelerating hydrodynamic section, where acceleration occurs through systems that initiate coaxial Bernoulli effects. The second flow (40% of the total flow), also under a pressure of at least 3 bar (45 psi), enters the second hydrodynamic section coaxial to the first.

The device performs a dynamic process of sequential homogenization of the liquid fuel or fuel blend flow. At the first stage, homogenization is achieved through turbulence-level homogenization within the pipeline. Such a process is absent in all previously known homogenization devices and technologies and represents one of the key innovative aspects of the technology, confirmed in the fundamental intellectual property documents of Hryhorii Baranovskyi, the developer of the technological elements.

After this stage, the homogenized flow of liquid fuel or fuel blend is transformed into a hydrodynamic vortex tube by means of the integrated vortex generator and directed toward the high-pressure pump of a diesel or other internal combustion engine operating at pressures from 2000 to 3000 bar (29,000––43,500 psi). There, the second stage of dynamic in-flow homogenization takes place, reducing the particle size in the homogenized flow to less than one micron. According to the key parameters of the flow, the resulting liquid becomes equivalent in properties to a homogeneous nanoscale fuel emulsion.

A similar system can also operate in the fuel lines of boilers, burners, turbines, and other thermodynamic devices and equipment.

The homogenization process occurs in less than one second and does not disturb the natural interactions within the homogenized liquid fuel or fuel blend. The process takes place at a stable temperature or, under certain ratios, with a reduction in the temperature of the combustible liquid or fuel mixture.

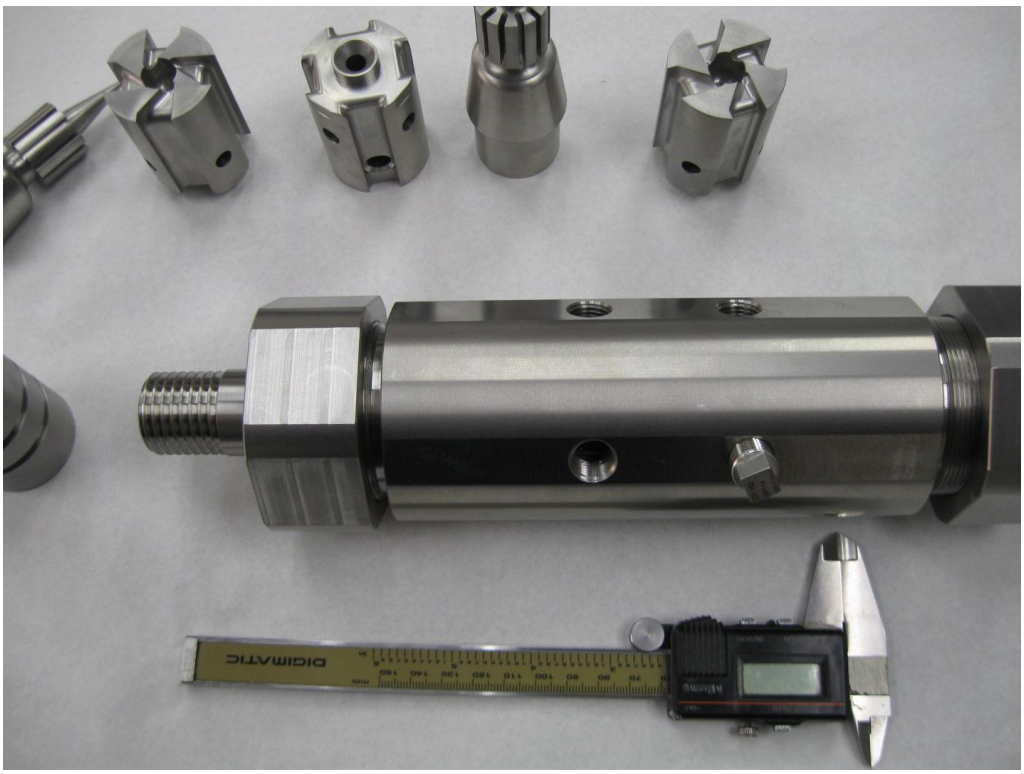
The entire dynamic homogenization process is achieved through the creation of special turbulent hydrodynamic conditions within the fuel or fuel blend flow, without disrupting the chemical and physical equilibrium between its components.

Advantages of the dynamic homogenization process proposed by Hryhorii Baranovskyi compared to existing technologies:

- Existing technologies do not include a turbulence-level dynamic homogenization stage, which means they cannot perform homogenization directly within the fuel pipeline of an internal combustion engine;
- The second stage of the homogenization process takes place under pressure at least twice as high as that required for homogenization at the nanoscale particle level;
- The particle sizes (globules) in the liquid fuel or fuel blend homogenized using the proposed technology are uniform within the range of 70–120 nanometers and do not tend to agglomerate, whereas existing technologies produce particle size variations exceeding a factor of ten, ranging from 0.2 to 2 microns;
- All stages of dynamic homogenization can be carried out directly in the fuel pipeline of an internal combustion engine, for example between the fuel pump and the high-pressure pump, without requiring special modifications to the engine design (the same applies to other types of thermodynamic equipment);
- During the dynamic homogenization process, the temperature of the homogenized liquid fuel or fuel blend does not increase;
- The dynamic homogenization device allows additional components to be introduced simultaneously during homogenization, such as water, methanol, ethanol, or synthetic kerosene;
- The dynamic homogenization device has minimal dimensions, is more convenient to operate than existing systems, and provides optimal conditions for installation and maintenance;
- The device for dynamic homogenization of liquid fuels and fuel blends is significantly less expensive than existing equipment designed for the same purpose.
- The device can also be used for technological homogenization before introducing fuel or fuel blends into industrial equipment for the production of other hydrocarbon products.

As can be seen from the presented photographs, the dimensions of the device are extremely compact in relation to its performance capacity (the images show devices with a throughput of 1000 liters per hour).

Figure 4.



Original Device for Dynamic Homogenization

Based on the concept developed by Hryhorii Baranovskyi, a device for the dynamic homogenization of liquid fuels and fuel blends has been designed, manufactured, and repeatedly tested.

All elements and components of the device are produced using standard CNC machining equipment without the use of specialized technologies or special cutting tools.

Stainless steel is used as the structural material, allowing the installation of the device and associated systems in environments with increased corrosion exposure, such as marine vessels.

The device is extremely compact, with dimensions that allow it to be integrated into virtually any internal combustion engine, including both stationary engines (such as marine engines) and engines installed in vehicles of all types.

Figure 5.

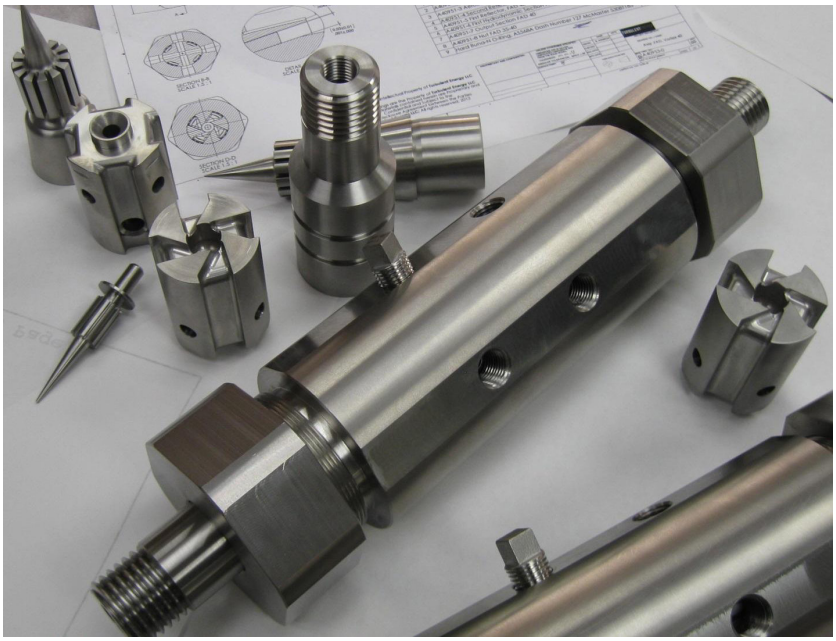


Figure 6.

The device does not require any additional elements or components for operation and can be installed directly in the fuel pipeline of an internal combustion engine, between the fuel pump and the high-pressure pump.

All inlet and outlet connection elements of the device are standardized. Installation of the device on an internal combustion engine does not require special training, tools, or equipment.

The device contains no moving parts and can be manufactured in any required dimensional scale.

The device can be produced using standard CNC manufacturing equipment, and its production, assembly, and quality control do not require specialized technologies, materials, or tools.

Figure 7.

Thermodynamic Effect of Using Homogenized Fuel (Produced by the Dynamic Homogenization Device).

After homogenization, the fuel burns uniformly, without the formation of local zones containing larger dispersion fractions after injection.

As a result, the combustion process proceeds 35–40% faster, and efficient heat extraction is accelerated in the same proportion (the results were confirmed in more than 300 test cycles using a modern production diesel engine with a displacement of 2.5 liters).

The homogenization technology operates equally effectively in both standard engines and engines equipped with exhaust gas recirculation systems.

In the event of unintended water contamination in the fuel tank, dynamic homogenization forms a micro-emulsion within milliseconds before the fuel enters the high-pressure pump, completely eliminating any harmful effects of water contained in the fuel emulsion on engine operation (confirmed in more than 60 test cycles on a modern 2.5-liter production diesel engine).

While maintaining effective engine power, the micro-emulsion significantly reduces soot emissions in exhaust gases (up to 97%) and nitrogen oxide emissions (up to 35%), shortens the complete combustion cycle, and accelerates heat extraction (confirmed in more than 300 full reverse-cycle tests on a modern 2.5-liter production diesel engine).

The use of the homogenization system also makes it possible to achieve the same spray dispersion quality at pressures 35––45% lower than the conventional 1600––2000 bar injection pressure range.

This effect reduces the power consumption required for operating the high-pressure pump and also demonstrates potential energy savings for turbines and turbo-generators operating at injection pressures of 30 bar and above.

Environmental Effect of Using Homogenized Fuel

The use of a dynamic liquid fuel homogenization device in the fuel systems of internal combustion engines significantly reduces the toxicity of exhaust gases and may enable previously manufactured vehicles, including those that have been in long-term operation, to meet modern environmental standards.

Sequential Dynamic Homogenization Process in a Modern Diesel Engine

The device for dynamic homogenization of fuel and fuel blends in a modern diesel engine is installed in the fuel line between the fuel pump and the high-pressure pump.

In this configuration, the fuel flow leaving the fuel pump is divided into two streams. One stream, representing 60% of the total fuel flow, is directed into the central axial inlet of the dynamic fuel homogenization device, while the second stream, representing 40% of the total flow, enters

the integrated inlet consisting of four radial channels.

After homogenization, the fuel burns uniformly, without the formation of local zones containing larger dispersion fractions after injection.

As a result, the combustion process proceeds 35–40% faster, and efficient heat extraction is accelerated in the same proportion (confirmed in more than 60 test cycles on a modern production diesel engine with a displacement of 2.5 liters).

The homogenization technology operates equally effectively in both standard engine configurations and engines equipped with exhaust gas recirculation systems.

Sequential Dynamic Homogenization Process in a Modern Gasoline Engine

The device for dynamic homogenization of fuel and fuel blends in a modern gasoline engine is installed in the fuel line between the fuel pump and the high-pressure pump.

In this configuration, the fuel flow leaving the fuel pump is divided into two streams. One stream, representing 60% of the total fuel flow, is directed into the central axial inlet of the dynamic fuel homogenization device, while the second stream, representing 40% of the total flow, enters the integrated inlet consisting of four radial channels.

The homogenization technology operates equally effectively in both standard engine configurations and engines equipped with exhaust gas recirculation systems.

Application of the Dynamic Homogenization Process in Internal Combustion Engines Using Ethanol–Gasoline Fuel Blends

Ethanol, even of high quality, contains a certain amount of water. Before mixing with gasoline, ethanol is a relatively stable substance in which separation of water and alcohol does not occur.

However, an ethanol–gasoline blend is not completely stable, and under certain conditions, such as low temperatures, water may separate from the gasoline–ethanol mixture.

If a dynamic homogenization device is integrated into the engine system, the water separated in the fuel tank from the primary hydrocarbon fraction of the fuel blend is dynamically remixed with the hydrocarbon fractions within the device, transforming the resulting mixture into a micro- or nanoscale emulsion.

The combustion of such an emulsion generally occurs in a stable thermodynamic regime, without detonation and with reduced soot and nitrogen oxide emissions in the exhaust gases.

Application of the Dynamic Homogenization Process in Internal Combustion Engines Using Methanol–Gasoline Fuel Blends

Methanol, even of standard quality, contains virtually no water. Before mixing with gasoline, methanol is a relatively stable substance and, after mixing, generally does not separate from gasoline.

However, methanol–gasoline blends are not completely stable and, under certain conditions such as low temperatures, may tend to form clots or agglomerates.

The combustion of homogenized fuel generally occurs in a stable thermodynamic regime, without detonation and with reduced soot and nitrogen oxide emissions in the exhaust gases.

Application of the Dynamic Homogenization Process in Internal Combustion Engines Using Gasoline and Biofuel Blends (Currently the Most Important and Relevant Application)

Since these thermodynamic systems use fuel blends containing gasoline together with heavier biofuels and various types of viscous combustible biological materials, the formation of clots and agglomerates in such composite fuels occurs more intensively.

If a dynamic homogenization device is integrated into the thermodynamic system, the clots formed under certain conditions in the fuel tanks and consisting of the primary hydrocarbon fraction of the fuel blend are dynamically mixed with the remaining hydrocarbon fractions inside the device, transforming the clotted mixture into a homogeneous system of micro- or nanoscale particles.

The combustion of homogenized fuel generally occurs in a stable thermodynamic

regime, without detonation and with reduced soot and nitrogen oxide emissions in the exhaust gases.

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