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Section 1. Biology

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IDENTIFICATION OF NEW BACILLUS VELEZENSIS ENDOPHYTIC STRAINS – PROBIOTIC AGENTS FOR SOYBEAN SYMBIOTIC SYSTEMS DEVELOPMENT

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Abstract

The aim of the study was to identify soybean endophytic bacteria and determine the prospects for their use in soybean cultivation. It was found that the isolated strains belong to Gram-positive spore-forming bacteria that ferment a wide range of carbohydrates. Based on whole-genome sequencing and phylogenetic analysis, the endophytes were identified as *Bacillus velezensis* IMV B-8134 and IMV B-8135. This Whole Genome Shotgun project has been deposited at DDBJ/ENA/GenBank under the accession JBPUKF000000000 and JBRIKE000000000, BioProject PRJNA1294768. The application of the isolated endophytic strains together with nodule bacteria in soybean cultivation under biotic and abiotic stresses showed a positive effect on adaptation and productivity of plants. This provides grounds for further research on strains as promising for the creation of biological agents in soybean cultivation.

Keywords: *Bacillus velezensis, endophytes, Glycine max (L.) Merr., whole-genome sequencing, stress-protective potential*

Introduction

Endophytic bacteria are described as those isolated from surface-sterilized plant tissues and inhabiting the intercellular space in various plant organs without harming the phytopartner (Santoyo et al., 2016). They promote the growth of the host plant and help it tolerate stressful conditions, having unique metabolic abilities: synthesis of phytohormones and siderophores, mobilization of phosphates, nitrogen fixation, biocontrol of phytopathogens, protection against abiotic stresses (Burragoni & Jeon, 2021). Due to these properties, endophytes have great probiotic potential for use in the cultivation of various agricultural crops (Afzal et al., 2019). The wide range of metabolic activity of endophytes determines the prospects for their use in plant growing, biotechnology, medicine, and remediation measures. Despite the fact

that the metabolic potential of endophytic bacteria has been studied sufficiently, there is limited data on their practical application as commercial biological products in agricultural practice. Therefore, the search for new effective strains of endophytic bacteria is currently relevant.

The aim of the study was to identify soybean endophytic bacteria and determine the prospects for their use in soybean cultivation.

Methods

The strains *Bacillus* sp. 4 and *Bacillus* sp. 5 were isolated from surface-sterilized nodules of cultivated soybean (*Glycine max* (L.) Merr.), grown in the Kyiv region (Ukraine). The morphology of the isolates was studied by light microscopy of Gram-stained 1-day-old cultures grown on agarised mannitol-yeast nutrient medium. The physiological and biochemical properties were studied using the Vitek 2 BioMérieux automated system. The ability of strains to utilize citrate and carbohydrates was tested according to Gordon et al. (1973), and gelatin hydrolysis was assessed according to Khatarkar et al., 2017).

DNA extraction was performed using the DNeasy® UltraClean® Microbial Kit. The quality of the extracts was assessed using a NanoDrop spectrophotometer (Thermo Fisher Scientific, Waltham, MA, USA). Whole-genome sequencing was performed on the Illumina NovaSeq platform (2×150 bp, GATC Biotech, Konstanz, Germany), yielding approximately 6.2 million paired reads. Genome assembly was performed using BacFlux v1.1.8, including quality control, completeness and contamination assessment, and taxonomic verification. Primary assembly was performed using SPAdes v4.0.0; the average genome coverage was 420.53 ± 133.01.

The similarity of the genomes of the studied isolates to the type strain *B.velezensis* FZB42 was checked using the Orthologous Average Nucleotide Identity using USEARCH (OrthoANIu) service, available at http://www.ezbiocloud.net/tools/ani (Yoon et al., 2017).

Results

In terms of morphological properties, both strains *Bacillus* sp. 4 and *Bacillus* sp. 5 are Gram-positive bacilli measuring 2,0×0,7 and 2,3×0,5 μ***m*** respectively, located singly or in chains, with central endospores that do not change the shape of the cell. On meat-peptone and potato agar media, they form rounded beige matte colonies with a diameter of 5–7 mm and a paste-like consistency. When grown on meat-peptone broth, the strains form a film.

It was found that *Bacillus* sp. 4 and *Bacillus* sp. 5 are capable of liquefying gelatin, fermenting lactose, D-mannitol, L-arabinose, D-glucose, D-ribose, as well as hydrolyzing aesculin and growing at 6.5% NaCl, while they are not capable of fermenting D-tagatose and inulin (Table 1).

Table 1. *Physiological and biochemical properties of new isolates Bacillus sp. 4 and Bacillus sp. 5 and type strain B. velezensis sp. nov. CR-502T*

Reaction	***Bacillus sp.* 4**	***Bacillus sp.* 5**	***B. velezensis sp. nov. CR-502^{T*}***
Citrate utilization	+	+	–
Gelatin hydrolysis	+	+	+
Lactose utilization	+	+	+
D-mannitol utilization	+	+	+
L-arabinose utilization	+	+	+
D-glucose utilization	+	+	+
Glycogen utilization	+	–	+
D-mannose utilization	–	+	+
D- melezitose utilization	–	+	–
N-acetyl-D-glucosamine utilization	+	–	–

Reaction	*Bacillus sp.* 4	*Bacillus sp.* 5	*B. velezensis sp. nov. CR-502*^{T*}
D-tagatose utilization	–	–	–
Inulin utilization	–	–	–
D-ribose utilization	+	+	+
Aesculin utilization	+	+	+
Growing in 6,5% NaCl concentrations	+	+	+

*Note: "+" – test positive, "-" – test negative, *– according to data (Ruiz-Garcia et al., 2005).*

All the physiological and biochemical properties of *Bacillus* sp. 4 and *Bacillus* sp. 5 strains corresponded to those of spore-forming bacteria of the *Bacillus subtilis* group. In most tests, the results coincided with the properties of the typical strain *B. velezensis* sp. nov. CR-502^{T} (Ruiz-Garcia et al., 2005).

To determine the species boundaries of the studied bacteria, the results of molecular genetic studies were used, in particular, the average nucleotide identity (ANI) index (Table 2). ANI calculation involves fragmenting genome sequences, searching for nucleotide sequences, aligning and determining the identity of nucleotide sequences of the genomes of two prokaryotic strains during the classification and identification of bacteria.

Table 2. *Identification of nucleotide genome sequences of new isolates Bacillus sp. 4 and Bacillus sp. 5 and strain B.velezensis FZB42*

Compared genomes	*B.velezensis* FZB42 / *Bacillus* sp. 4	*B.velezensis* FZB42 / *Bacillus* sp. 5
OrthoANIu value (%)	98.86	98.87
Genome length (bp) of *B.velezensis* FZB42	3 917 820	
Genome length (bp) of endophytic strain	3 967 800	4 038 180
Average aligned length (bp)	2 646 004	2 777 125
Genome coverage (%) of *B.velezensis* FZB42	67.54	70.88
Genome coverage (%) of endophytic strain	66.69	68.77

Comparative genomic analysis using OrthoANIu showed a high level of similarity between both endophytic isolates and the strain *B.velezensis* FZB42. OrthoANIu values were 98.86% for *Bacillus* sp. 4 and 98.87% for *Bacillus* sp. 5 with 66.69 and 68.77% reciprocal coverage, indicating that the studied strains and *B. velezensis* FZB42 belong to the same species.

Thus, according to whole-genome sequencing and phylogenetic analysis, the isolated endophytes were identified as *Bacillus velezensis* IMV B-8134 and IMV B-8135 and deposited in the D. K. Zabolotny Institute of Microbiology and Virology of the NAS of Ukraine Depository.

This Whole Genome Shotgun project has been deposited at DDBJ/ENA/GenBank under the accession JBPUKF000000000; BioSample SAMN50125348 and JBRIKE000000000; BioSample SAMN52024099 respectively; BioProject PRJNA1294768. The versions described in this paper are versions JBPUKF000000000 and JBRIKE000000000.

The results of *in vitro* and *in vivo* experiments showed that the studied endophytic strains exhibited a wide range of antagonistic activity against bacterial and fungal pathogens of soybean diseases (Shevchuk et al., 2025 b). As shown by studies on soybean cultivation under drought conditions in the Kyiv region (Ukraine), the use of complex seed inoculation with nodule bacteria together with the studied endophytic bacteria contributed to an increase in adaptive potential, better

formation of a symbiotic system and an increase in yield of soybean variety Sculptor by 36.2% (Shevchuk et al., 2025a).

Discussion

Representatives of the *Bacillus velezensis* species have agricultural, biotechnological, and ecological applications due to their probiotic effects: stimulating plant growth, improving nutrition, suppressing pathogens, etc. Correct identification of *B. velezensis* strains is important due to their potential applications. More often, *B. velezensis* strains are isolated from the rhizosphere soil of various plants, including soybeans. In contrast to these data, our research concerns strains isolated directly from surface-sterilized soybean nodules. Data on the use of *B. velezensis* in soybean cultivation are very limited. In particular, it has been reported that *B. velezensis* S141, isolated from a soybean rhizosphere in Thailand, enhanced soybean growth by stimulating nodule formation with the *Bradyrhizobium diazoefficience* USDA110 strain (Kondo et al., 2023). The co-inoculation showed the highest efficiency in nitrogen fixation, number of nodules, dry root weight, and total dry plant weight (Sibponkrung et al., 2020). It has been established that *B. velezensis* enhances the symbiosis of *B. japonicum* with soybean by secreting flavonoids, in particular rutin, which modulates the expression of nodule genes (Cheng et al., 2025).

Comparing these data with ours, it should be noted that our studies were conducted in a different climatic zone. We also used other strains of nodule bacteria, *B. japonicum*. However, we obtained similar results regarding the positive effect of co-inoculation on soybean plants. This indicates a general pattern of complementary synergistic action of nodule and endophytic bacteria. In addition, our data add to the knowledge on how co-inoculation of soybean seeds with endophytic *B. velezensis* together with nodule bacteria increases stresses tolerance and yield of plants under adverse conditions.

Conclusion

Non-rhizobial endophytic bacterial strains were isolated from soybean nodules. Based on morphological, cultural, physiological, and biochemical characteristics, as well as whole-genome sequencing and phylogenetic analysis, the isolates were identified as *B. velezensis* IMV B-8134 and *B. velezensis* IMV B-8135. Their positive effect on the symbiosis of soybean and rhizobia was revealed, which is manifested in the ability to maintain the physiological homeostasis of the phytopartner under adverse conditions and increase plant productivity. New *Bacillus velezensis* endophytic strains are prospective probiotic agents for the development of stress-protective biotechnologies.

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Section 2. Biotechnology

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QUALITATIVE AND QUANTITATIVE ANALYSIS OF COLLAGEN PROTEIN

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Abstract

This research mainly presents the results of the analysis of the quality and quantity of proteins extracted from cattle hide. The study focuses on the processing of cattle hide, which is considered an industrial waste, and the proper organization of collagen extraction. Additionally, the composition and purity of the extracted protein are assessed. The total nitrogen content in the sample was measured using the Kjeldahl method, and the total percentage of protein was calculated using a conversion factor (usually 6.25, or a factor adjusted to the research conditions). Furthermore, the amount of water-soluble proteins in the mixture was analyzed using the Lowry method at a wavelength of 570 nm with a UV–Vis 1900i instrument. The individual amino acids in the mixture were quantitatively and qualitatively analyzed using HPLC at a wavelength of 269.4 nm.

Keywords: *hayvon terisi, oqsil, kollagen, aminokislota, Kjeldahl method, Lowry method, spektroskopiya, xromatografiya*

Introduction

Protein deficiency remains a serious global 0issue among the world's population. Regional and socio-economic disparities are expressed in significantly varying indicators. This is influenced by people's lifestyles and ethnographic environments, ranging from protein biosynthesis in the body to the protein content of consumed products, as well as the consumption of protein-rich foods to prevent protein deficiency in humans. The quality of proteins and their bioavailability remain crucial factors. Proteins are not only produced as preparations but also used in enriching the composition of products, especially food products, improving their quality indicators, which has become one of the most relevant issues today.

Looking at global indicators and trends, in 2019, the global prevalence of protein deficiency was estimated to affect approximately 147 million people, resulting in about 212,000 deaths. Between 1990 and 2021, the components of food products related to protein deficiency had a significant impact on age-related disease rates (54.9%) and mortality rates (72.2%). During this period, the rate of protecting consumers' rights (DALY) decreased to 51.9%. Regional disparities and threats of protein deficiency are particularly evident in areas with low socio-demographic indexes (SDI), especially in many countries of South Asia and Africa. In 2021, South Asia had the highest intensity of people suffering from protein deficiency. The reasons and impacts include food shortages, unbalanced diets, economic constraints, and insufficient consumption of animal protein products. The negative consequences include slowed growth (especially in children), weakened immune systems, rapid muscle mass loss in the elderly, lower quality of life, and the development of various blood, bone, and skin diseases.

Currently, scientific research is being conducted to address these issues. Over the past three years, global trends have been moving in a downward direction, but the protein problem persists in low-income regions. In 2024–2025, the situation is expected to worsen due to rising food prices and climate change. In the future, to meet protein needs, there is an increasing focus on alternative protein sources such as animal tissues, plant samples, microbial biomass, and protein-rich substitutes (e.g., insects, microalgae, synthetic proteins).

Literature Review

Collagen is an important structural component in the extracellular matrix and is one of the most widely distributed proteins in the animal kingdom. It is crucial for the shape, structure, and mechanical properties of tissues that aid in structural formation. Collagen has been known to be used in various fields such as food, medicine, and others since ancient times. A prominent example is "catgut", sutures made from the cut and cleaned submucosa of sheep intestines, which are fully absorbable by the body (British Standard 757: 1975). Despite the possibility of allergic reactions like unwanted immune responses to xenotransplants, collagen-based biomaterials have been processed into different morphologies and are currently widely used as barrier or filler materials in reconstructive surgery (Buljan, J., Reich, G. & Ludvik J., 2000).

Animal by-products, particularly those from meat supply chains and the residual materials such as skin, bones, hooves, intestines, and other animal organs, are rich in collagen proteins and are widely used in food industry product manufacturing (Dubois, M., 1992; Ericson, C.M., 1993). However, processing these by-products can be a complex technological task and might lead to low-quality protein samples, such as collagen with low nutritional value (Gault, N. F. S. & Lawrie, R. A., 1980).

The largest volume of waste in skin processing comes from bovine hides. This large base of raw material is sufficient for collagen extraction. However, from an environmental standpoint, such production poses challenges, as the residues left after protein extraction can lead to ecological problems. According to scientific literature, 40–60% of the protein content may remain in these residues, which is difficult to process and extract in industry (Dubois, M., 1992; Eduard Roether, Darmstadt, Germany. Hwang, K. T. & Regenstein, J. M., 1993).

Collagen extraction through partial degradation (hydrolysis) results in fewer protein residues. This process is also suitable for processing small amounts of collagen waste such as skin scraps, short and long fibers, bones, and others. Protein extraction from by-products of the meat industry (heart, kidneys, liver, lungs, stomach, and intestines) can be achieved by dissolving at temperatures not exceeding 60 °C under mild alkaline conditions. Protein hydrolysates are prepared through enzymatic (pepsin, papain, neutralase, or alcalase) treatment of degreased tissues at 50 °C. The yield of soluble hydrolysates is very high (up to 85%), and the resulting protein hydrolysates show no significant loss of amino acids (Gault, N. F. S. & Lawrie, R. A., 1980; Langmaier, F., Mladek, M., Kolomaznik, K. & Maly, A., 2002 a).

Under enzymatic reaction conditions, hydrolysis leads to partial breakdown of collagen, resulting in low-solubility collagen with an average molecular mass of 300 kDa. This

protein mixture can be used as a component in cosmetics (moisturizing films regulating the water content in skin). Collagen preparations, collagen fibers, or hydrolysates can also be successfully used as carriers for food or cosmetic supplements (British Standard 757: 1975; Lowry O. H., Rosebrough N. J., Farr A. L., Randall R. J., 2011).

Deep processing of collagen is typical in gelatin production, where the protein molecule is broken down to a molecular mass of 220 kDa. This collagen is not only used in gelatin production but is also increasingly added to food products as a thickening agent or "flavor extender" and is used in pharmaceuticals, food supplements, and as a biologically degradable material for capsule coating in cosmetics (Langmaier, F., Mladek, M., Kolomaznik, K. & Maly, A., 2002a; Lowry O. H., Rosebrough N. J., Farr A. L., Randall R. J., 2011).

The main goal of this article is to analyze the composition of collagen from bovine skin using modern methods and to organize scientific research aimed at improving its industrial applications

Methods

The Lowry method is the most widely used and highly sensitive technique among those used to determine protein content. It is based on two reactions: the Biuret reaction and the colorimetric reaction with Folin's reagent, which specifically interacts with tyrosine and cysteine residues.

After preparing 5 series of standard solutions from the water extracts of collagen protein samples, 1 ml of each solution is taken and 4 ml of solution A and B mixture is added. The liquids are mixed thoroughly using a vortex shaker (Vortex-Dlab-MX-S) and left at room temperature for 10 minutes. Then, 0.4 ml of Folin's reagent is added using an automatic pipette, and the mixture is allowed to react for 20–30 minutes to form the color. Afterward, the optical density is measured at a wavelength of 670 nm using a UV–Vis 1900i spectrophotometer.

Determination of Total Protein Content. The method involves determining nitrogen content by Kjeldahl's method, followed by conversion to protein content. The essence of the method consists of digesting the organic substance of the sample with boiling concentrated sulfuric acid to form ammonium salts, converting ammonia into ammonium, distilling it into an acid solution, quantitatively determining ammonia using a titrimetric method, and calculating the nitrogen content in the examined material.

A precise sample of the ground homogenized sample for analysis was weighed in a test tube with an error of no more than 0.1%. The sample was quantitatively transferred into a Kjeldahl flask. The subsequent experiments were conducted according to the methodological instructions (Methods of control. 2004).

Processing of Results: The mass fraction of nitrogen (X) in the sample was calculated as a percentage of its mass during the distillation of ammonia into sulfuric acid using the formula.

$$X = \frac{(V_1 - V_0) \times K \times 0.0014 \times 100}{M}$$

Volume V_0 – the volume of the 0.1 mol/L sodium hydroxide solution used to titrate the 0.05 mol/L sulfuric acid in the control experiment, in milliliters (ml).

Volume V_1 – the volume of the 0.1 mol/L sodium hydroxide solution used to titrate the sulfuric acid in the sample solution, in milliliters (ml).

K – correction factor for the titration of the 0.1 mol/L sodium hydroxide solution.

0.0014 – the amount of nitrogen equivalent to 1 ml of 0.05 mol/L sulfuric acid solution.

M – the mass of the sample in grams (Steven A., Cohen Daviel J., 1988).

Free Amino Acid Isolation. Precipitation of proteins and peptides from the aqueous extract of the samples was conducted in centrifuge tubes. For this, 1 ml of the sample was mixed with 1 ml (accurate volume) of 20% trichloroacetic acid (TCA). After 10 minutes, the precipitate was separated by centrifugation at 8000 rpm for 15 minutes. Then, 0.1 ml of the supernatant was lyophilized. The hydrolysate was concentrated, and the dry residue was dissolved in a mixture of triethylamine-acetonitrile-water (1:7:1) and dried. This operation was repeated twice for neutralizing the acid. The phenylthiocarbamyl derivatives (PTC) of amino acids were obtained by re-

acting with phenylthiocyanate according to the method of Steven A. and Cohen Daviel. Identification of the amino acid derivatives was performed using HPLC.

HPLC conditions: Chromatograph Agilent Technologies 1200 with a DAD detector, 75x4.6 mm Discovery HS C18 column. Solvent A: 0.14 M sodium acetate + 0.05% TEA, pH 6.4; Solvent B: CH3CN. Flow rate: 1.2 ml/min, absorption at 269 nm. Gradient %B/min: 1–6%/0–2.5 min; 6–30%/2.5–40 min; 30–60%/40.1–45 min; 60–60%/45.1–50 min; 60–0%/50.1–55 min

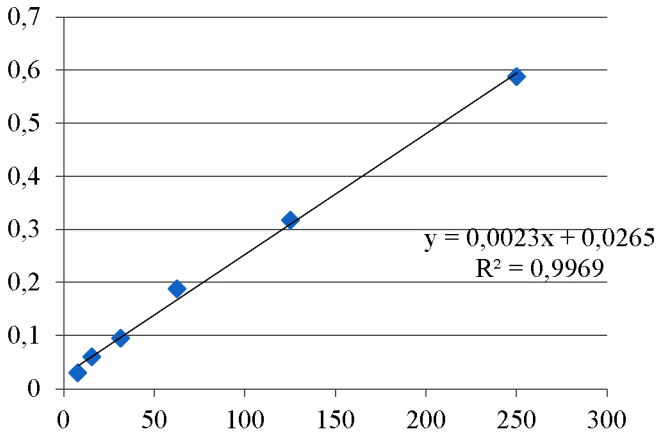
Results and Discussion

The text you're referring to describes the method for determining soluble protein content, specifically focusing on a calibration curve for albumin in the range of 0.025 mg to 0.3 mg. This curve is used to calculate the amount of soluble proteins in a sample based on the obtained formula. This method is commonly used for protein analysis, where the albumin standard helps quantify proteins in complex mixtures such as the collagen extracted from animal tissues, as described in your document.

Figure 1. *UB – Spectroscopic analysis process*

A graph was created after performing the Lowry reaction with 5 series of standard protein solutions. The optical density was plotted on the ordinate axis, and the protein concentration was plotted on the abscissa axis, with points marked according to the FEK indicator. The standard used was egg albumin that had been recrystallized four times (Methods of control. 2004).

Figure 2. *Calibration curve for determining the amount of water-soluble proteins in the fruit of Maclura*



To analyze the amount of water-soluble proteins in the sample extracted from the bovine hide, Brazilian-produced collagen protein was selected for comparative study. The spectral average light absorption errors of the protein quantities were determined, and the following formula was used to calculate the amount of water-soluble protein in the composition:

For the Uzbekistan sample, the protein calculation in Sample 1 is based on the light absorption coefficient.

$$y = 0{,}0023x + 0{,}0265$$
$$R^2 = 0{,}9969$$

"Overall average in the sample (average result of 3 repeated measurements):" 0,516

Calculation: $0{,}516 = 0{,}0023x + 0{,}0265$

$$0{,}516–0{,}0265 + 0{,}4895$$
$$0{,}4895=0{,}0023x$$

$$x = \frac{0{,}4895}{0{,}0023} = 212{,}8\, mkg / mg$$

Taking into account that the initial obtained amount is 250 µg, the final calculation is performed as follows:

$$212{,}8 * 4 = 851{,}2$$

"The amount of water-soluble protein in the first sample was determined to be 851.2 µg/ml in the protein solution with a volume of 1 ml.

The amount of water-soluble protein in the Brazilian sample, Sample 2, was determined as follows:

Protein calculation based on the light absorption coefficient.":

$$y = 0{,}0023x + 0{,}0265$$
$$R^2 = 0{,}9969$$

"Average in the sample (average result of 3 repeated measurements).: 0,408

Calculation: $0{,}483 = 0{,}0023x + 0{,}0265$

$$0{,}408–0{,}0265 + 0{,}3815$$
$$0{,}4565=0{,}0023x$$

$$x = \frac{0{,}4565}{0{,}0023} = 198{,}47\, mkg / mg$$

"Considering that the initial amount was 250 µ*g*, the final calculation is as follows:

$$198{,}47 * 4 = 793{,}91$$

The amount of water-soluble protein in the second sample was calculated to be 793.91 µg/ml in a 1 ml solution.

According to the protein content measured by the Lowry method and analyzed using UV-spectroscopy, the water-soluble protein amounts in both samples were found to be similar. Considering that both solutions were prepared in a 1:1 ratio, it was determined that the first sample contained 851.2 µg/ml, while the second sample contained 793.91 µg/ml of water-soluble protein.

In numerous literature sources, the water-soluble portion of collagen protein is reported to range from 0.8 to 1.3 mg/ml. The amounts of water-soluble proteins in both analyzed samples are consistent with the data presented in the literature, and the variation in protein amounts can be attributed to the method of isolation and the quality of the sample.

The total protein content was analyzed using the Kjeldahl method. The final test result was calculated as the arithmetic average of five parallel test results. The obtained results were analyzed up to three decimal places, with two decimals used for rounding

$$X_3 = \frac{X_1 \times 100}{100 - W}$$

X_1 – the mass fraction of nitrogen in the test sample, %;

W – the moisture content of the test sample, %.

The mass fraction of protein (Y) was calculated in percent using the following formula:

$$Y = K\, CHX$$

"The nitrogen-to-protein conversion coefficient: with the average lipid content, is 6.38."

Table 1. *Nitrogen Content and Protein Percentage in Sample Compositions (%)*

No.	Samples	N (%)	protein (%)
1.	Uzbekistan	12.2	77.68
2.	Brazil	14.73	93.82

The difference in nitrogen and protein content in the samples can be clearly seen through the following diagram based on the table data.

The total protein content in the sample extracted from cattle hide was analyzed, using collagen protein produced in Brazil as a reference standard for comparison.

Both samples extracted from cattle hide were analyzed in the same way, with the nitrogen content of the Uzbekistan sample determined to be 12.2%. It was calculated that the total protein content in this sample was

77.68%. In comparison, the nitrogen content of the Brazil sample was found to be 14.73%, and the total protein content in this sample was calculated to be 93.82%. Chromatographic analysis was conducted to determine the amount of free amino acids in the extracted protein from the cattle hide. The resulting chromatogram was compared to a standard chromatogram developed for amino acids, and the peaks observed in the chromatogram corresponded to specific amino acids at specific time intervals, confirming the consistency of the analysis.

Figure 3. *Results of protein analysis using the Kjeldahl method*

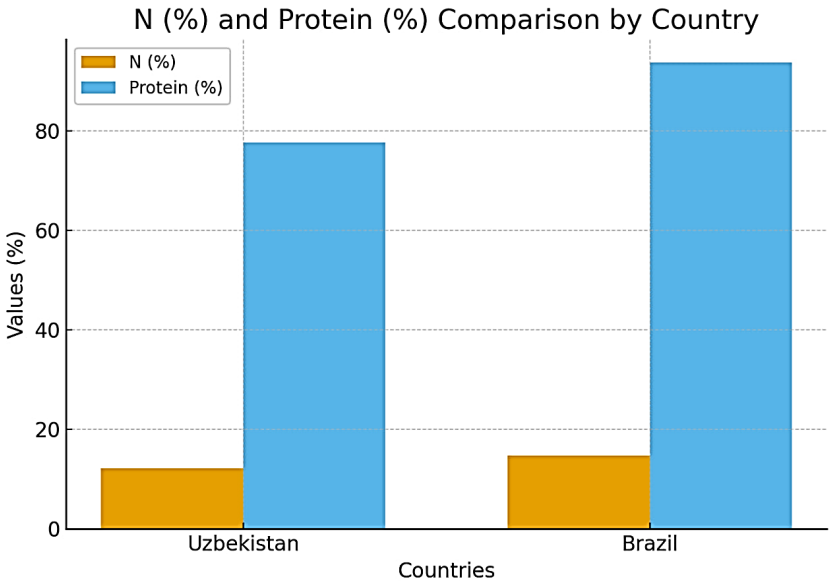
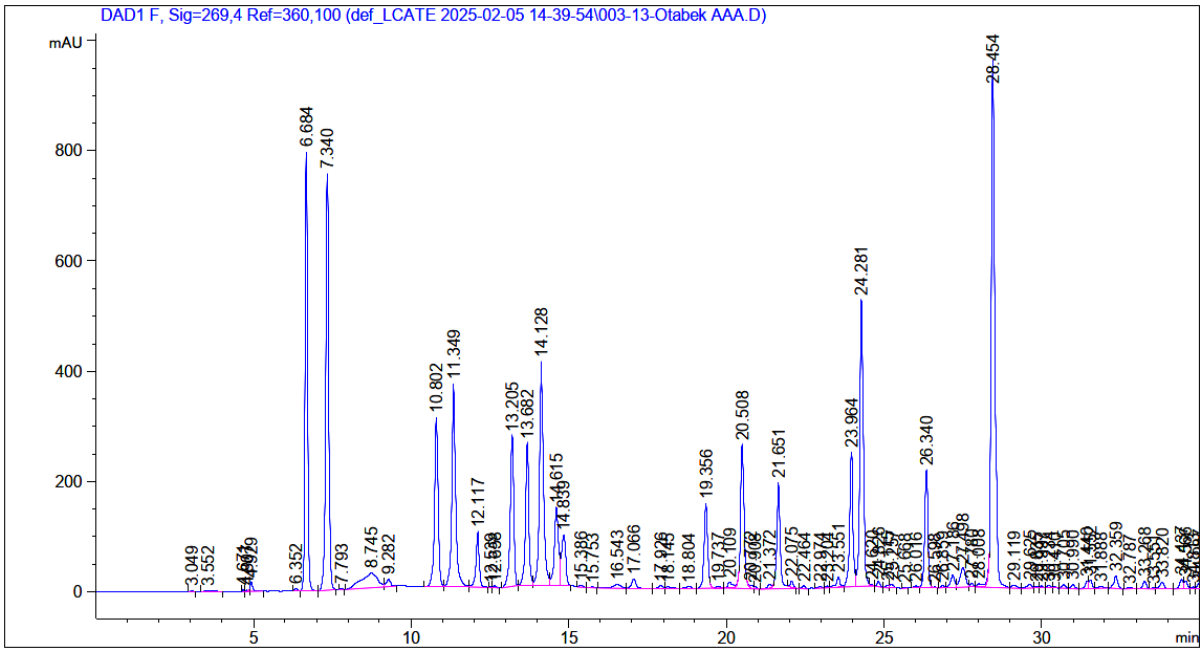


Figure 4. *Chromatogram of free amino acids in the collagen proteins extracted from bovine hide (HPLC analysis)*



This research work, which focuses on the quality and quantity analysis of amino acids in collagen proteins, is a result of using High-Performance Liquid Chromatography (HPLC). The exact quantities of amino acids are provided in Table 2.

If we pay attention to the data in the table, we can see that there is a distinct dif-

ference in the amino acid content between the two samples. This can be explained by the fact that the Brazilian sample was processed using a two-stage enzymatic hydrolysis method. As for the cause of the high level of asparagine acid in the Uzbekistan sample (107.537 mg/g), this can be attributed to the acidic environment generated during the process. Similarly, a significant difference in cysteine content is observed, where the Brazilian sample contains a considerably higher amount (258.3738 mg/g). Other statistical results from the study can be seen in the table above. The final conclusion of this research suggests that enzymatic approaches lead to an increase in the amount of free amino acids in the collagen protein.

Table 2. *Amino acid content in the samples*

Names of Amino Acids	Uzbekistan	Brazil
	Concentration mg/g	
Asparagine	107.537	26.33114
Glutamine	77.273	23.2169
Serine	16.329	41.8192
Glycine	35.172	14.02153
Asparagine	0	0
Glutamine	0	0
Cysteine	23.959	258.3738
Threonine	19.699	8.884653
Arginine	12.842	13.41166
Alanine	15.097	39.24491
Proline	13.558	60.50574
Tyrosine	9.695	15.05598
Valine	22.622	57.44512
Methionine	23.564	3.748216
Histidine	7.464	14.10037
Isoleucine	21.685	26.37163
Leucine	52.709	49.4889
Tryptophan	0	0
Phenylalanine	13.477	16.94842
Lysine	48.553	10.16152
Total	521.235	679.1297

Conclusion:

Through the extraction of collagen protein and its subsequent physical, chemical, and biochemical analyses, it is possible to study the full bio-functions of the protein, which can improve its significance in the production of food and other industrial products. Based on the results of the study, it can be concluded that the enzymatic approach in collagen extraction increases the quantity of free amino acids in the protein.

In the analysis of water-soluble protein content using the Lowry method, considering that each solution was prepared in a 1:1 ratio, the amount of water-soluble protein in sample 1 was found to be 851.2 μg/mg, and in sample 2 it was 793.91 μg/mg. Several literature sources show varying amounts of soluble collagen protein in the range of 0.8–1.3 mg/ml. The obtained results for water-soluble proteins correspond with those values found in the literature, and also demonstrated the changes in

the protein's properties depending on the extraction method and the quality of the sample.

Both samples extracted from bovine skin were analyzed in the same manner, with the Uzbekistan sample showing a nitrogen content of 12.2%, and the total protein content in the sample being calculated at 77.68%. The nitrogen content in the Brazilian sample was found to be 14.73%, with the total protein content calculated to be 93.82%.

Using High-Performance Liquid Chromatography (HPLC), this study also determined the quality and quantity of amino acids in the collagen protein. Based on the findings, it can be concluded that the enzymatic approach in collagen extraction increases the amount of free amino acids within the collagen protein.

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Section 3. Chemistry

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EFFECT OF INITIAL REAGENT RATIOS AND TEMPERATURE ON THE YIELD IN THE SYNTHESIS OF COPPER–COBALT-CONTAINING PHTHALOCYANINE COMPOUNDS: FTIR SPECTRAL ANALYSIS OF THE OBTAINED PRODUCT

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Abstract

This article investigates the effect of initial reagent ratios and temperature on the synthesis of a bimetallic copper–cobalt phthalocyanine (Cu–Pc–Co) compound. The synthesis process was carried out within the temperature range of 180–240 °C using different molar ratios of phthalic anhydride (FA), urea (Kar), $CuCl_2$, and $CoCl_2$. The results showed that both temperature and the ratio of initial reagents significantly influence the product yield. In particular, the maximum yield of 87,1% was achieved at an FA: Kar: $CuCl_2$: $CoCl_2$ ratio of 1:6,0:1:2 and a temperature of 220 °C. Based on graphical analysis, the optimal reaction conditions were determined. These findings demonstrate that controlling synthesis parameters plays an important role in improving the efficiency of bimetallic phthalocyanine production. Infrared (IR) spectral analysis of the synthesized copper–cobalt phthalocyanine compound confirmed the presence of characteristic phthalocyanine ring bonds (–C–N–C–), as well as metal–nitrogen coordination bonds (Cu–N and Co–N).

Keywords: *Phthalocyanine, phthalic anhydride, urea, reaction yield, temperature, $CuCl_2$, $CoCl_2$, bimetallic, IR spectrum, stretching vibration, bending vibration*

Introduction

Phthalocyanines (Pc) belong to a class of tetrapyrrolic macrocyclic compounds characterized by a delocalized 18 π-electron system, in which all atoms of the molecule are arranged in a single geometric plane. Due to their electroactivity, high thermal stability, and resistance to light, phthalocyanine derivatives are widely used in the production of dyes, sensors, catalysts, solar cells, and anticorrosion coatings. Among metal-containing phthalocyanines, copper phthalocyanine (CuPc) and cobalt phthalocyanine (CoPc) are of particular importance (Fazlı H. et al. 2023; BaŞ, Hüseyin, Nuran Kahrİman, and Zekeriya BiyiklioĞlu. 2020; Gokce, C., Aslan, Y., Durmuş, M., 2015).

Bimetallic phthalocyanines, containing two different metal ions within their structure, exhibit enhanced electronic and physicochemical properties and are capable of functioning effectively even under complex conditions (Author(s) Unknown. 20220). In recent years, pigments based on bimetallic phthalocyanines have attracted increasing interest among researchers due to their high thermal and chemical stability, intense coloration, and efficient catalytic properties (Maqbaş, H., Kahriman, N., Bıyıklıoğlu, Z., 2020; Author(s) Unknown. 2022). In this study, phthalocyanine complexes containing copper and manganese ions were synthesized. The influence of different ratios of initial reagents and temperature on the reaction yield was investigated. It was found that a higher product yield was achieved at an initial reagent ratio of 3:3:0.5:0.5 and a reaction temperature of 240 °C. However, when the temperature was increased to 260 °C, a decrease in the reaction yield was observed (Nazarov N. I., Fayziyev J. B., Beknazarov H. S., Mirzoyeva G. A., 2025). Copper phthalocyanine and nickel phthalocyanine were synthesized, and the IR spectra of the obtained compounds were analyzed. The analysis revealed characteristic absorption bands corresponding to the bonds between atoms forming the phthalocyanine molecule: for copper phthalocyanine, absorption bands were observed at 3047 cm^{-1} (aromatic –CH), 1609 cm^{-1} (–C=C–), 1504 cm^{-1} (–N=), and 1408, 1329 cm^{-1} (–C=C–N–); for nickel phthalocyanine, bands appeared at 3059 cm^{-1} (aromatic –CH), 1620 cm^{-1} (–C=C–), 1488 cm^{-1} (–N=), and 1380, 1301 cm^{-1} (–C=C–N–) (Aleksanyan K. G. i dr., 2018). Although data on the synthesis and spectroscopic properties of bimetallic phthalocyanines have been reported, the optimal conditions for their synthesis, including the ratio of initial reagents and the effect of reaction temperature on product yield, have not been fully investigated (Zengin, H., Kantekin, H., 2011).

Materials and Methods

Phthalic anhydride, urea, $CuCl_2 \cdot 2H_2O$, $CoCl_2 \cdot 6H_2O$, and 0,05 g of catalyst were weighed in the required proportions, and the synthesis of phthalocyanines was carried out. The data on the effect of the initial reagent ratios and temperature on the yield during the synthesis of copper–cobalt ion-containing bimetallic phthalocyanine complexes are presented in Table 1.

Table 1. *Effect of FA: Kar: $CuCl_2$: $CoCl_2$ ratio and temperature on the yield of phthalocyanine*

No.	FA: Kar: $CuCl_2$: $CoCl_2$	T, ˚C	ω,%	No.	FA: Kar: $CuCl_2$: $CoCl_2$	T, ˚C	ω,%
1.	1: 4,0: 1: 2	180	25,1	9.	1: 6,0: 1: 2	180	67,9
2.		200	28,2	10.		200	80,2
3.		220	31,5	11.		220	87,1
4.		240	36,9	12.		240	81,2
5.	1: 5,3: 1: 2	180	46,2	13.	1: 7: 1: 2	180	64,5
6.		200	59,8	14.		200	75,9
7.		220	64,3	15.		220	79,2
8.		240	54,5	16.		240	72,6

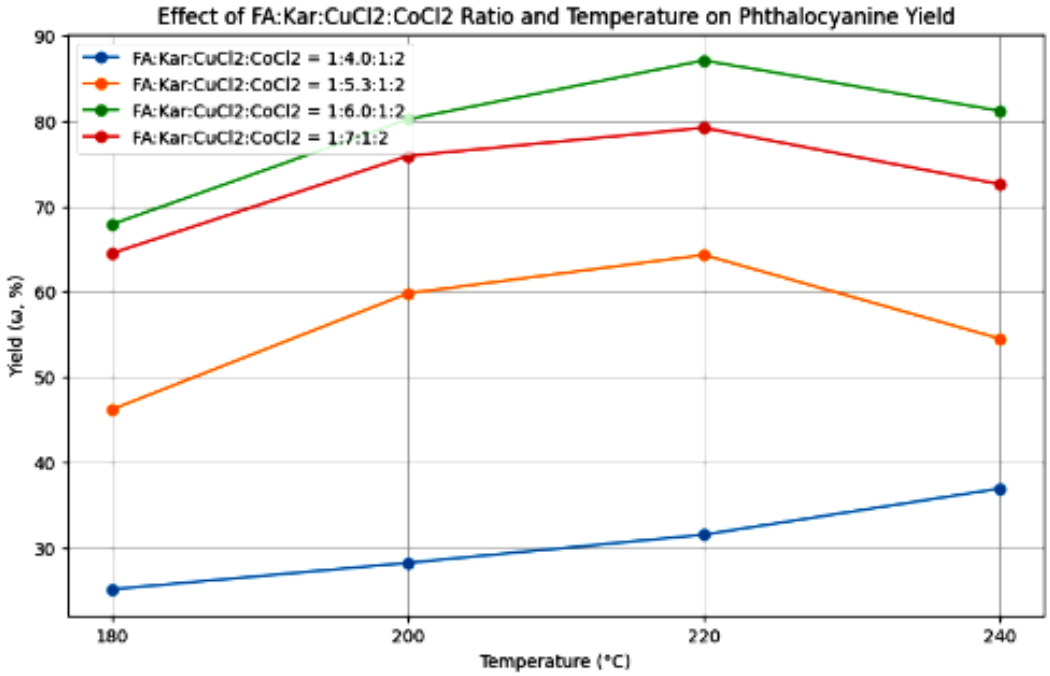
Effect of Initial Reagent Ratios and Temperature on the Yield of Phthalocyanine in the Synthesis of Copper–Cobalt-Containing Phthalocyanine

The table presented above shows the results of the analysis of the relationship between temperature (T, °C) and product yield (ω, %) in the synthesis of bimetallic phthalocyanine in the presence of copper(II) chloride and cobalt(II) chloride. In this analysis, the synthesis results obtained using different ratios of FA: Kar: $CuCl_2$: $CoCl_2$ (1:4.0:1:2; 1:5.3:1:2; 1:6.0:1:2; 1:7:1:2) were compared. It was observed that an increase in the amounts of phthalic anhydride and urea leads to an increase in product yield. In all cases, the yield increased as the reaction temperature rose from 180 °C to 220 °C. However, at 240 °C, a decreasing trend in product yield was observed, which may indicate a reduction in product mass or the occurrence of thermal degradation at higher temperatures. When the initial reagent ratios were 1:6,0:1:2 and 1:7:1:2, and the reaction was carried out at 220 °C, the highest product yields (87,1% and 79,2%, respectively) were obtained. This suggests that an optimal balance between phthalic anhydride and urea plays a crucial role in achieving maximum yield.

The presence of metal salts is essential for phthalocyanine synthesis. The optimal temperature range for the reaction was found to be 180–220 °C, while temperatures above 240 °C resulted in a decrease in product yield.

The diagram above illustrates the effect of FA: Kar: $CuCl_2$: $CoCl_2$ ratios on the yield (ω, %) of bimetallic phthalocyanine complexes as a function of temperature. The obtained results indicate that both the composition of the reaction medium and temperature significantly influence the formation of the macrocyclic ring.

Figure 1. *Graphical Representation of the Effect of Initial Reagent Ratios and Temperature on the Yield of Copper–Cobalt-Containing Phthalocyanine Complex*



The diagram above illustrates the effect of FA: Kar: $CuCl_2$: $CoCl_2$ ratios on the yield (ω, %) of bimetallic phthalocyanine complexes as a function of temperature. The obtained results indicate that both the composition of the reaction medium and temperature significantly influence the formation process of the macrocyclic ring.

According to the results, at initial reagent ratios of 1:6,0:1:2 and 1:7.0:1:2, the maximum reaction yields of 87.1% and 79.2%, respectively, were achieved at 220 °C. This suggests that, at 220 °C, the cyclotetramerization process proceeds under kinetically and thermodynamically optimal conditions. In particular, at the 1:6,0:1:2 ratio, the sufficient amount of urea

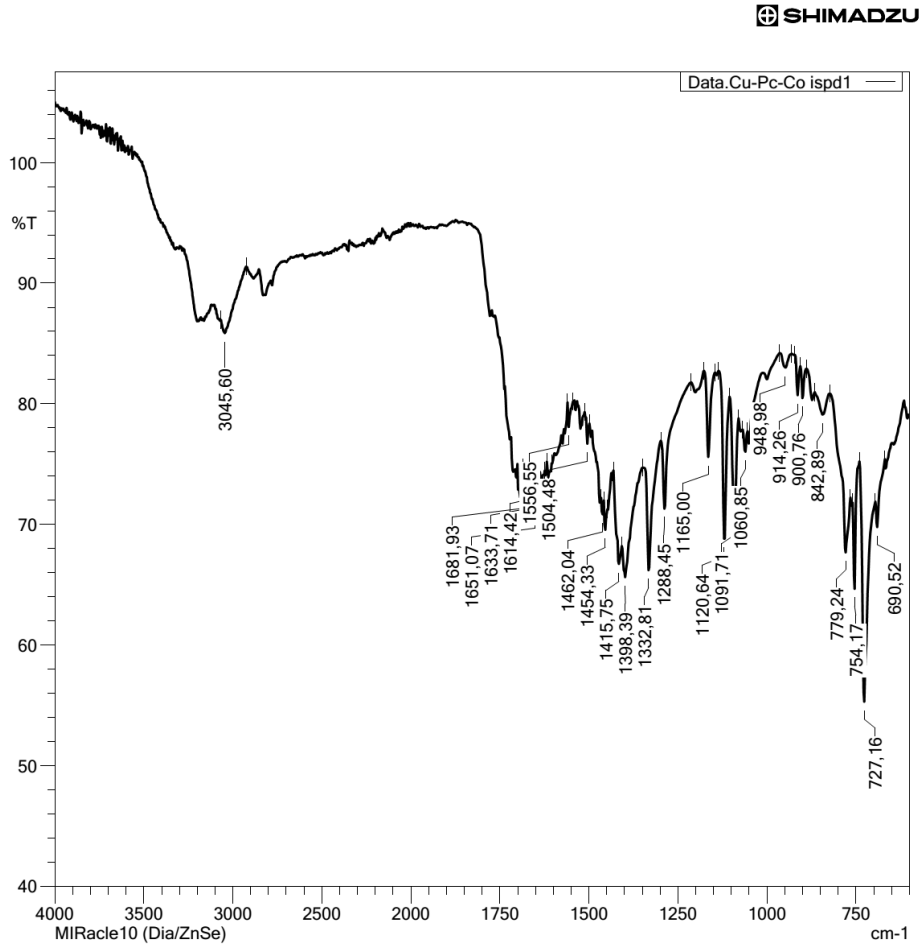
ensures complete conversion of phthalonitrile intermediate products and promotes coordination of metal ions (Cu^{2+} and Co^{2+}) with the macrocyclic ligand center.

When the temperature was increased to 240 °C, a decrease in product yield was observed for all studied ratios. This may be attributed to partial thermal degradation of the macrocyclic system, activation of side reactions, and decomposition of intermediate compounds. Although the process becomes kinetically faster at 240 °C, the stability of the product decreases, leading to reduced overall selectivity.

A similar trend was observed for the ratios 1:4.0:1:2 and 1:5,3:1:2; however, the product yields in these cases were significantly lower. Based on the obtained results, it can be concluded that the optimal conditions for the synthesis of copper–cobalt-containing bimetallic phthalocyanine complexes are an initial reagent ratio of 1:6,0:1:2 and a temperature of 220 °C, at which the yield reaches 87,1%. These conditions can therefore be considered optimal for the synthesis of Cu–Pc–Co complexes.

The FTIR spectrum of the synthesized copper–cobalt phthalocyanine (Cu–Pc–Co) complex was recorded in the range of 4000––600 cm^{-1}. The observed absorption bands correspond to the characteristic stretching and deformation vibrations of the phthalocyanine ring (Figure 2).

Figure 2. *FTIR Spectrum of Copper–Cobalt-Containing Phthalocyanine*



The absorption band at 3045 cm^{-1} corresponds to the C–H bonds of the aromatic ring. Since no vibrations characteristic of aliphatic groups were observed in the phthalocyanine molecule, these signals can be attributed solely to the aromatic ring of phthalocyanine.

The peaks in the range of 1681–1614 cm^{-1} correspond to the stretching vibrations of the C=N bonds in the phthalocyanine molecule, as well as the C=C bonds of the aromatic ring. The slight shift of these absorption frequencies toward higher wavenumbers indicates the formation of coordination bonds with the

Cu^{2+} and Co^{2+} ions. In metal-free phthalocyanine, these absorption peaks typically occur around 1620–1600 cm^{-1}. Upon formation of the metal complex, the peaks shift to higher frequencies, confirming coordination interactions between the metal and nitrogen atoms in the phthalocyanine macrocycle.

The symmetric and asymmetric absorption bands in the range of 1556–1504 cm^{-1} correspond to the C=C and C=N bonds within the phthalocyanine ring. Absorption bands at 1462–1398 cm^{-1} are associated with the stretching vibrations of C–C bonds and deformation vibrations of C–N bonds in the aromatic ring, confirming the formation of the phthalocyanine macrocycle.

The band at 1332–1288 cm^{-1} corresponds to deformation vibrations of the C–N bonds, while the absorption region at 1165–1060 cm^{-1} is related to vibrations of –C–H and C–N–C bonds within the phthalocyanine ring. Peaks in the range 948–842 cm^{-1} correspond to –C–H bonds and metal–nitrogen coordination interactions. In particular, the 900–850 cm^{-1} region indicates the formation of Cu–N and Co–N bonds. Finally, the absorption bands at 754–690 cm^{-1} correspond to deformation vibrations of the M–N (Cu–N, Co–N) bonds in the phthalocyanine complex, confirming the successful formation of metallophthalocyanines.

Conclusion

In this study, the synthesis of bimetallic copper–manganese phthalocyanines was successfully carried out, and the optimal conditions for the synthesis were determined. It was found that, at an initial reagent ratio of 1:6:1:2 and a reaction temperature of 220 °C, the yield of the resulting phthalocyanine reached 87,1%. These results indicate that these conditions are optimal for the synthesis of copper–cobalt-containing bimetallic phthalocyanines.

FTIR spectral analysis of the obtained compound showed that the main vibration bands in the 1300–1500 cm^{-1} region, corresponding to C–N and C=N bonds, are associated with the aromatic ring of phthalocyanine. Shifts in these bands, along with absorption in the 690–640 cm^{-1} region, confirm the coordination of the central metal ions with the ligand and the formation of the metallophthalocyanine complex.

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Section 4. Materials science

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A STUDY ON A CLASS OF FOURTH ORDER NONLINEAR DIFFERENTIAL EQUATIONS

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Abstract

This work is dedicated to the study of certain properties of the almost everywhere solution to a one-dimensional mixed problem for one class of fourth order nonlinear equations. The almost everywhere solution of mixed problem under consideration is sought in the form of Fourier series. After applying Fourier method, the problem of finding unknown Fourier coefficients $u_n(t)\,(n=1,2,...)$ of sought almost everywhere solution $u(t,x)$ is reduced to solving some countable system of nonlinear integral equations.

Keywords: *fourth order nonlinear equation, one-dimensional mixed problem, almost everywhere solution, Fourier method*

The study examines certain properties of the almost everywhere solution to the following one-dimensional mixed problem:

$$\begin{cases} u_{tx}(t,x)-\alpha\, u_{xxxx}(t,x)=F(t,x,u(t,x),u_x(t,x),u_{xx}(t,x),u_{xxx}(t,x)) \\ \qquad\qquad (0\le t\le T,\ 0\le x\le \pi), \qquad (1) \\ u(0,x)=\phi(x)\ (0\le x\le \pi), \qquad (2) \\ u(t,0)=u(t,\pi)=u_{xx}(t,0)=u_{xx}(t,\pi)=0\ \ (0\le t\le T), \qquad (3) \end{cases}$$

where $\alpha>0$ is a fixed number, $0<T<+\infty$; F and ϕ are given functions, and $u(t,x)$ is a sought function.

Definition

We define an almost everywhere solution of problem (1)-(3) as a function $u(t,x)$ with the following properties:

a) $u(t,x)$, $u_x(t,x)$, $u_{xx}(t,x)$, $u_{xxx}(t,x)$, $u_t(t,x)$' $u_{tx}(t,x) \in C([0,T]\times[0,\pi])$; $u_{xxxx}(t,x)$' $u_{txx}(t,x) \in C([0,T];L_2(0,\pi))$;

b) equation (1) is satisfied almost everywhere in $[0,T]\times[0,\pi]$;

c) all the conditions (2) and (3) are satisfied in ordinary sense.

Previous studies have addressed various aspects of mixed problems for nonlinear equations. In particular, the paper by (Aliyev S., Heydarova M., and Aliyeva A., 2024), the local (in small) existence of a classical solution to the mixed problem under consideration was established.

It should also be mentioned that some methodological ideas used in the present study are based on the approaches developed in the works of (Davis P. L., 1971), (Aliyev S., Aliyeva A., and Abdullayeva G., 2019),(Khudaverdiyev K. I. and Sadikhov M. N., 2008), (Khudaverdiyev K. I., Heydarova M.N, 2008), (Azizbayov, E.I.,2019) and (Azizbayov, E.I., 2022).

As the system $\{\sin nx\}_{n=1}^{\infty}$ forms a basis in the space $L_2(0,\pi)$, then it is obvious that every almost everywhere solution $u(t,x)$ of problem (1)-(3) has the following form:

$$u(t,x)=\sum_{n=1}^{\infty}u_n(t)\sin nx\,, \tag{4}$$

where

$$u_n(t)=\frac{2}{\pi}\int_0^{\pi}u(t,x)\sin nx dx\,. \tag{5}$$
$$(n=1,2,...;\ t\in[0,T])$$

In the next, after applying Fourier method, the finding of functions $u_n(t)$ $(n=1,2,...)$ is reduced to solving the following countable system of nonlinear integral equations:

$$u_n(t)=\phi_n\cdot e^{-\alpha n^2 t}-\frac{2}{\pi n^2}\times$$
$$\times\int_0^t\int_0^{\pi}\mathrm{P}(u(\tau,x))\sin nx\cdot e^{-\alpha n^2(t-\tau)}dxd\tau \tag{6}$$
$$(n=1,2,...;\ t\in[0,T])\,.$$

where

$$\phi_n\equiv\frac{2}{\pi}\int_0^{\pi}\phi(x)\sin nx dx\ \ (n=1,2,...), \tag{7}$$

$$\mathrm{P}(u(t,x))\equiv F(t,x,u(t,x),u_x(t,x),u_{xx}(t,x),u_{xxx}(t,x)), \tag{8}$$

with notations (4) and (5) taken into account.

Using the definition of almost everywhere solution of problem (1)-(3), it is to prove the following

Theorem

If $u(t,x)=\sum_{n=1}^{\infty}u_n(t)\sin nx$ is any almost everywhere solution of problem (1)-(3), then functions $u_n(t)$ $(n=1,2,...)$ satisfy on the $[0,T]$ system (6).

Proof

Let $u(t,x)=\sum_{n=1}^{\infty}u_n(t)\sin nx$ be any almost-everywhere solution of problem (1)-(3). Then, obviously, the functions $u_n(t)$ $(n=1,2,...)$ are defined by relation (5). First, we adopt the notation

$$\mathrm{P_n}(u;t)\equiv\frac{2}{\pi}\int_0^{\pi}P(u(t,x))\sin nx dx \tag{9}$$
$$(n=1,2,...;\ t\in[0,T])\,,$$

and the operator P is defined by relation (8).

Next, multiplying both parts of equation (1) by the function $\frac{2}{\pi}\sin nx$, integrating the resulting equality over x from 0 to π and using the notation (9), we obtain that for any fixed $(n=1,2,...)$ for any $t\in[0,T]$:

$$\frac{2}{\pi}\int_0^{\pi}u_{txx}(t,x)\sin nx dx=\frac{2}{\pi}\{u_{tx}(t,x)\cdot\sin nx\}_{x=0}^{x=\pi}-$$
$$\frac{2}{\pi}n\int_0^{\pi}u_{tx}(t,x)\cos nx dx=-\frac{2n}{\pi}\int_0^{\pi}u_{tx}(t,x)\cos nx dx=$$
$$=-\frac{2n}{\pi}\{u_t(t,x)\cdot\cos nx\}_{x=0}^{x=\pi}-\frac{2n}{\pi}n\int_0^{\pi}u_t(t,x)\sin nx dx=$$
$$=-\frac{2n^2}{\pi}\int_0^{\pi}u_t(t,x)\sin nx dx= \tag{10}$$
$$=-n^2\cdot\frac{d}{dt}\left(\frac{2}{\pi}\int_0^{\pi}u(t,x)\sin nx dx=\right)=n^2\cdot u_n'(t)\,;$$

$$\frac{2}{\pi}\int_0^{\pi}u_{xxxx}(t,x)\sin nx dx=\frac{2}{\pi}\{u_{xxx}(t,x)\cdot\sin nx\}_{x=0}^{x=\pi}-$$

$$-\frac{2}{\pi}\cdot n\cdot\int_0^{\pi}u_{xxx}(t,x)\cos nxdx=-\frac{2n}{\pi}\cdot\{u_{xx}(t,x)\cdot\cos nx\}_{x=0}^{x=\pi}-$$

$$-\frac{2n}{\pi}\cdot n\cdot\int_0^{\pi}u_{xx}(t,x)\sin nxdx=-\frac{2n^2}{\pi}\cdot\int_0^{\pi}u_{xx}(t,x)\sin nxdx=$$

$$=-\frac{2n}{\pi}\cdot\{u_x(t,x)\cdot\sin nx\}_{x=0}^{x=\pi}+\frac{2n^2}{\pi}\cdot n\cdot\int_0^{\pi}u_x(t,x)\cos nxdx=$$

$$=\frac{2n^3}{\pi}\cdot\int_0^{\pi}u_x(t,x)\cos nxdx=\frac{2n^3}{\pi}\cdot\{u_x(t,x)\cdot\cos nx\}_{x=0}^{x=\pi}+$$

$$+\frac{2n^3}{\pi}\cdot n\cdot\int_0^{\pi}u(t,x)\sin nxdx=\frac{2n^4}{\pi}\cdot\int_0^{\pi}u(t,x)\sin nxdx=$$

$$=n^4\cdot\left(\frac{2}{\pi}\int_0^{\pi}u(t,x)\sin nxdx=\right)=n^4\cdot u_n(t).\quad(11)$$

Due to (10) – (11), relation (9) takes the form:

$$-n^2u_n'(\tau)-\alpha n^4\cdot u_n(t)+\mathrm{P_n}(u;t),$$

hence

$$u_n'(t)+\alpha n^2u_n(t)=$$
$$=-\frac{1}{n^2}\cdot\mathrm{P_n}(u;t)\ (n=1,2,...;t\in[0,T]).\quad(12)$$

And from the initial condition (2) it follows that

$$u_n(0)=\frac{2}{\pi}\int_0^{\pi}u(0,x)\sin nxdx=$$
$$=\frac{2}{\pi}\int_0^{\pi}\phi(x)\sin nxdx=\phi_n\ (n=1,2,...).\quad(13)$$

Thus, the functions $u_n(t)$ $(n=1,2,...)$ are the solution of the Cauchy problem (12), (13).

Easy to show the problem of (12), (13) is equivalent to system (6). The theorem is proved.

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FROM ADAPTIVE INTERFACES TO CYBER-PHYSICAL SYSTEMS: INNOVATIONS TRANSFORMING FLIGHT SAFETY

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Abstract

The rapid digitalization of aviation has redefined how pilots interact with flight systems, transitioning from manual control to highly automated and cognitively adaptive environments. Building on the foundations of adaptive human–machine interfaces and recent advances in neuroergonomics, this paper explores the continuum from adaptive cockpit design to the emergence of fully integrated cyber-physical systems (CPS) that redefine flight safety. Drawing on the pioneering works of Alain Philippe Gruchet, the study examines how adaptive visualization, psychophysiological monitoring, and cognitive modeling have evolved into closed-loop architectures capable of perceiving, reasoning, and acting in synchrony with the human operator. The discussion highlights three major shifts: from static to adaptive information display, from task-based to state-based automation, and from isolated systems to interconnected CPS networks. By synthesizing developments across avionics engineering, cognitive neuroscience, and safety certification, the paper identifies how these innovations collectively create a new paradigm of "human-aware" aviation technology.

Keywords: *adaptive cockpit interface; cognitive ergonomics; neuroadaptive systems; cyber-physical systems (CPS); pilot monitoring; flight safety; human–machine interaction; artificial intelligence in aviation*

Introduction: from human factors to intelligent cockpits

For over a century, the history of aviation safety has mirrored the evolution of the human–machine relationship. Early mechanical cockpits, composed of individual dials and analog instruments, reflected a world in which human skill and perception alone governed flight. As digital avionics emerged in the late twentieth century, the emphasis shifted toward automation, redundancy, and error reduction through computer assistance. Yet, despite this technological progress, human factors have remained at the heart of both progress and tragedy in aviation. Investigations of major accidents, from

pilot disorientation in fully automated airliners to lapses of attention in high workload conditions, have consistently revealed that the interface between human cognition and machine logic determines the boundary between safety and catastrophe.

The central challenge in modern flight operations is cognitive management. Pilots operate within an environment of compressed time, fluctuating workload, and dense informational streams. Automation can lighten the burden of repetitive control, but it also reconfigures the nature of the pilot's role, from continuous actor to supervisory controller. This shift, often described as the "paradox of automation," introduces a dual vulnerability: underload during routine phases, when vigilance declines, and overload during rare but critical anomalies, when the operator must suddenly regain manual control under stress. Traditional avionics were not designed to account for these dynamic fluctuations of human performance. Instead, they assumed the operator's cognitive state as constant – a static node in an otherwise dynamic system.

The research trajectory pioneered by Alain Philippe Gruchet addresses precisely this asymmetry. His works, spanning adaptive cockpit visualization, cognitive load monitoring, and neuroadaptive human–machine systems, articulate a vision of the cockpit as a living, responsive organism – a system that senses, interprets, and adapts in real time to the psychophysiological state of its human counterpart. In his concept of the "Neuroadaptive pilot cockpit interface", flight safety is no longer the sum of procedural compliance and mechanical reliability; it becomes a function of the harmony between neural signals, perceptual flow, and interface behavior. The cockpit, in this perspective, ceases to be a static display of data and evolves into an intelligent mediator of cognitive balance.

The emergence of adaptive interfaces represents a profound conceptual break in ergonomics. While earlier generations of automation reacted to environmental or system variables, neuroadaptive systems react to the operator's mind. They integrate multimodal physiological data – electroencephalographic activity, heart rate variability, galvanic skin response, eye tracking – to form a continuous picture of mental workload, stress, and fatigue. From this closed loop arises the possibility of dynamic visualization: the cockpit that simplifies itself when the pilot is overloaded, amplifies critical parameters under stress, or introduces multimodal cues to combat fatigue. By linking perception directly to interface configuration, Gruchet's approach closes the long-standing gap between human factors research and avionics engineering.

This new direction does not simply enhance ergonomics; it redefines safety as an emergent property of cognition-aware technology. The traditional logic of redundancy is complemented by cognitive redundancy, wherein the system compensates for the variability of human performance itself. The implication is transformative: safety becomes dynamic, sustained not by fixed procedures but by the ongoing alignment between human perception and machine intelligence. Gruchet's research situates this vision at the intersection of engineering precision and psychological insight, demonstrating that the next frontier in aviation safety lies not in stronger hardware or faster processors, but in systems that understand the human at their core.

The evolution from adaptive interfaces to cognitive systems

The path from adaptive interfaces to cognitive systems represents more than a sequence of technological upgrades, it embodies a paradigm shift in how safety, control, and intelligence are distributed across the human–machine ensemble. Early adaptive designs in aviation were rule-based: they responded to flight phase, environmental variables, or pilot inputs according to predefined logic trees. These systems could, for instance, declutter a display during takeoff or enlarge navigation data during approach, but they remained reactive to external context rather than internal cognition. Their intelligence was procedural rather than perceptual. In contrast, cognitive systems incorporate models of human thought and physiological feedback, enabling them to reason about the operator's internal state and adjust their behavior proactively.

Conceptually, this architecture anticipates the broader framework of cognitive cyber-physical systems. Traditional CPS integrate physical processes with embedded

computation and communication; cognitive CPS extend this integration to include human cognition as a controllable and measurable variable. The human operator is modeled as both a sensor and an actuator within the system loop. In flight operations, this means that pilot physiology influences not only the display but potentially the behavior of the aircraft itself. For example, if indicators of high stress coincide with a complex flight phase, automation might temporarily assume greater authority or delay non-essential tasks. Conversely, during low workload cruise, the system could re-engage the pilot through adaptive challenges or periodic checks to prevent vigilance decay. In both cases, safety arises from adaptive balancing – neither fully automated nor fully manual, but dynamically calibrated between the two.

In summary, the journey from adaptive interfaces to cognitive systems represents a transition from reactive ergonomics to predictive symbiosis. Where automation once replaced human functions, cognitive systems complement them; where static interfaces once displayed data, adaptive ones interpret and prioritize it; and where safety once relied on redundancy of hardware, it now depends on redundancy of understanding. This shift defines the essence of Gruchet's contribution: the recognition that the future of flight safety will be secured not by isolating the human from the system, but by embedding human cognition as a core variable within it.

Neuroadaptive design and pilot state monitoring

At the core of Alain Philippe Gruchet's vision lies the concept of the neuroadaptive cockpit – a system capable of sensing the pilot's physiological and cognitive state and adapting its behavior accordingly. This design unites human neurophysiology with avionics logic, transforming the cockpit into a cognitive ecosystem where perception, computation, and control operate in a closed feedback loop. Its fundamental purpose is not merely to record human performance but to stabilize it, to maintain the pilot's mental state within a safe operational envelope through continuous adaptation.

Neuroadaptive design begins with the reliable acquisition of psychophysiological signals. The architecture proposed in Gruchet's "Neuroadaptive pilot cockpit interface" integrates multiple channels – EEG, heart-rate variability (HRV), respiration, galvanic skin response (GSR), and eye-tracking – each capturing a distinct dimension of human cognition.

– EEG provides real-time access to cortical activity associated with workload, attention, and fatigue. Increases in theta activity or shifts in the theta/beta ratio often signal growing fatigue or cognitive disengagement, while elevated beta power may indicate stress or hyper-focus.

– HRV and respiration reflect autonomic balance: sympathetic dominance corresponds to stress, whereas stable high-frequency variability indicates calm control.

– GSR, measured via sensors on the control yoke or sidestick, quantifies acute arousal or surprise reactions.

– Eye-tracking monitors gaze dispersion, fixation durations, and blink dynamics.

The fusion of these modalities yields a comprehensive state vector representing both physiological activation and attentional focus. Redundancy across sensors ensures robustness against noise and artifact loss, an essential property in the vibrational, electromagnetically dense environment of an aircraft cockpit.

Once signals are acquired, they are processed within the cognitive analysis module, the analytical nucleus of the neuroadaptive loop. Here, filtered features, such us EEG band power, HRV indices, blink rates, reaction latencies, are fed into classification algorithms that map them to discrete cognitive states such as normal, stressed, fatigued, or overloaded. Gruchet's design accommodates both rule-based and machine-learning approaches: the first ensures deterministic behavior required for certification, while the second enables higher sensitivity and personalization.

In normal mode, the full set of parameters is displayed. Under stress, key indicators – airspeed, altitude, heading, enlarge and gain vivid color contrast. During fatigue, visual complexity is reduced while auditory or haptic cues are emphasized. When cognitive overload is detected, secondary data are hidden and the interface transitions to a minimalist view focused on flight-critical information.

Each of these scenarios corresponds to a cognitive-ergonomic hypothesis tested in simulators: by reducing visual clutter and enhancing salient cues, the interface shortens visual scan paths, lowers NASA-TLX workload scores, and halves error probability under turbulence conditions. The adaptation latency, less than 200 ms, ensures that the transition feels continuous rather than abrupt, preserving perceptual stability.

The dynamic visualization module closes the loop between analysis and perception. It modifies display layout, color coding, and modality balance in real time, forming a reciprocal dialogue between pilot and system. Every adaptation is logged with a timestamp and state context, creating a transparent trace of system reasoning. If a sensor fails or produces inconsistent values, a watchdog triggers safe degradation to the baseline, non-adaptive mode. This fail-safe principle ensures that adaptive automation never compromises essential situational awareness, a requirement aligned with aviation certification standards (e.g., ARP 4754A and DO-178C).

The neuroadaptive cockpit fundamentally redefines the distribution of cognitive labor between human and machine. Instead of treating the pilot as an exogenous disturbance in an otherwise deterministic control system, Gruchet's model places the pilot inside the loop as a dynamic variable to be stabilized. Physiological sensing becomes analogous to measuring aircraft attitude or velocity. In effect, the cockpit becomes a cognitive control system, where adaptation serves the same purpose as automatic flight control: damping oscillations, restoring equilibrium, and preventing excursions beyond safe limits, only now the regulated quantity is mental workload rather than altitude or airspeed. Empirical validation supports this analogy. Simulator studies referenced in the monograph demonstrate that when adaptive visualization is coupled with physiological monitoring, pilots maintain stable performance across longer sessions, exhibit fewer scanning regressions, and show quicker recovery from high workload events. Subjective measures, including perceived stress and fatigue, decline significantly compared to control conditions. These findings confirm that neuroadaptive design enhances not only the efficiency but the resilience of human performance.

As computing capabilities grow, the neuroadaptive model naturally extends toward prediction. Instead of reacting to instantaneous stress, future systems may forecast cognitive degradation minutes ahead by extrapolating trends in physiological signals and contextual factors. Such predictive adaptation will complete the transition from responsive assistance to preventive cognition management. In Gruchet's framework, this evolution converges with the broader discipline of cyber-physical intelligence, systems that perceive both their physical and human components as parts of a unified, self-regulating organism.

In sum, neuroadaptive design translates the human body and mind into measurable data streams, uses cognitive algorithms to interpret them, and closes the loop through adaptive visualization and control. The result is an aviation environment where safety is no longer ensured only by mechanical redundancy but by continuous cognitive equilibrium. By integrating sensing, reasoning, and adaptive actuation within one architecture, Gruchet's neuroadaptive cockpit exemplifies the first operational form of a cognition-aware cyber-physical system in aviation.

Integration of cyber-physical systems in aviation safety ecosystems

The transition from adaptive interfaces to fully integrated cyber-physical systems (CPS**)** marks the convergence of three technological trajectories: intelligent sensing, autonomous decision-making, and networked data exchange. In aviation, this convergence is transforming flight safety from a function of isolated subsystems into a property of interconnected, cognition-aware ecosystems. The neuroadaptive cockpit, as formulated in Gruchet's work, represents the human-centered node of this ecosystem – a cyber-physical hub where physiological and environmental data merge to sustain stability across the human–machine continuum.

CPS architectures invert this logic. They distribute computation and sensing across multiple, interacting layers and maintain continuous feedback between them. Within this network, adaptive cockpit interfaces

act as local intelligence nodes translating human state into system-level adjustments. The pilot's cognitive index, for instance, can inform not only the layout of cockpit displays but also autopilot behavior, alert scheduling, and even air-traffic management decisions. When aggregated across fleets, such data become a source of predictive analytics for fatigue risk, workload patterns, and operational safety margins.

The innovation lies in linking these domains through bidirectional information flows. Physiological signals – EEG, HRV, gaze, respiration – move upward from the human domain into the cyber layer, where they are analyzed by AI models. In parallel, flight data, environmental inputs, and automation status flow upward from the physical layer. The fusion of these data streams produces a unified situational model that drives adaptation downward: visual modifications to the cockpit, control adjustments, or task reallocation to automation. Such a loop constitutes a closed-loop cognition-centric CPS, where the stability criterion is not merely mechanical equilibrium but cognitive equilibrium – a balanced workload ensuring optimal decision-making. This redefinition of stability expands the classical control concept. Just as an autopilot regulates pitch and roll to maintain aerodynamic balance, the cognition-aware CPS regulates the pilot's mental load to maintain situational awareness and operational precision.

As Gruchet observed, this balance between automation and engagement defines sustainable safety. Over-automation isolates the human operator, while under-automation overwhelms them. Cognitive CPS architectures mediate this tension dynamically, assigning tasks not only by function but by cognitive readiness. The result is a distributed intelligence in which human and machine act as complementary agents in maintaining stability.

The integration of CPS into aviation safety raises formidable challenges for certification. Traditional regulatory frameworks such as DO-178C and ARP 4761 presuppose deterministic behavior and static requirements. Neuroadaptive and AI-driven systems violate these assumptions, they change behavior based on evolving human and contextual variables. Gruchet's design addresses this by enforcing bounded adaptivity: adaptation rules are predefined and verified, while the triggering thresholds can be tuned post-certification under controlled data governance.

A safe CPS must demonstrate three invariants:

1. Fail-safe behavior – any sensor or algorithmic fault reverts the system to a baseline, non-adaptive configuration.
2. Transparency – the pilot is always aware of the system's mode and can override it.
3. Traceability – all adaptive actions are logged for verification.

These principles allow regulators to treat the adaptive layer as an augmentative feature rather than a critical flight control component. In Gruchet's model, adaptation cannot hide or modify certified information; it can only reorganize presentation and modality. This constraint, while limiting autonomy, ensures certifiability. Future regulations, currently under study by EASA and FAA for AI integration, may formalize such bounded learning systems, defining "Level-1 adaptive" software as deterministic in structure but data-driven in calibration.

The cyber integration that empowers CPS also introduces new attack surfaces. Physiological data, if intercepted or corrupted, could lead to false adaptation or privacy breaches. Gruchet's architecture therefore incorporates immutable, encrypted logging and channel integrity monitoring to detect tampering. Moreover, adaptive systems must be designed to resist data poisoning, where corrupted inputs could trick classifiers into unsafe states.

The integration of cognition-aware CPS reconfigures the entire safety landscape. Instead of preventing discrete failures, the system mitigates drift, the gradual erosion of performance under fatigue, stress, or complacency that precedes most incidents. Real-time pilot state monitoring allows safety management systems to detect these precursors fleet-wide. Predictive analytics can then adjust rostering, workload policies, or training emphasis accordingly. At the macro level, this transforms safety from retrospective analysis to continuous optimization.

In this vision, Gruchet's neuroadaptive cockpit is not a self-contained invention but

a gateway technology. It anchors the human element within a digital safety network that extends from the pilot's neurophysiology to global flight-operation databases. By embedding cognition into the data loop, aviation evolves toward a model of resilient intelligence, systems that learn not only from mechanical parameters but from the rhythms and limits of the human mind.

Future directions: AI, autonomy, and ethical horizons

As adaptive interfaces mature into fully integrated cyber-physical systems, aviation enters a new era of cognitive autonomy, in which machines are not only automated but aware of the human beings they serve. This evolution will redefine every level of flight safety, from individual pilot performance to global operational resilience. The neuroadaptive architecture outlined in Gruchet's research represents a transitional form, a bridge between human-centered automation and autonomous intelligence that understands and respects human cognitive limits. The next frontier extends this intelligence beyond the cockpit, linking it to networked AI agents, predictive analytics, and ethically governed ecosystems.

Experiments like the "AdaptiveCoPilot" concept already demonstrate how combining pilot workload indices (e.g., fNIRS or EEG-derived metrics) with LLM reasoning can produce context-sensitive verbal support. Imagine a flight deck where the AI agent not only recognizes that the pilot is stressed during a go-around but also explains why the display has simplified itself, providing reassurance and transparency in human language. This mutual intelligibility between human and system could dissolve the last cognitive barrier between operator and automation.

Cognitive autonomy also entails distributed cooperation between machine intelligences. Within a fleet, AI copilots could share anonymized pilot-state data, creating a collective learning framework. If recurrent stress patterns appear during particular approach procedures, the system could adjust guidance cues fleet-wide before incidents occur. Gruchet's principle of immutable logs thus scales into a global safety nervous system – a distributed memory of human-machine interactions continually refining itself.

One of the most tangible drivers of adaptive and CPS technologies is the industry's movement toward single-pilot operations (SPO). Economic and logistical pressures, combined with advances in automation, have prompted research into reducing cockpit crew without compromising safety. However, SPO intensifies the cognitive demands on the remaining pilot, who must simultaneously manage control, communication, and monitoring tasks.

Here, neuroadaptive systems become not optional but essential. They act as cognitive load balancers, dynamically redistributing tasks between human and automation based on measured workload. During a complex approach, the system could automatically handle radio communication or checklist management; during low-demand cruise, it could reengage the pilot with supervision tasks to maintain alertness.

As neuroadaptive and CPS technologies grow more pervasive, they challenge fundamental notions of autonomy and privacy. The continuous collection of neural and biometric data raises the specter of cognitive surveillance, the risk that information meant for safety enhancement could be repurposed for performance evaluation or disciplinary oversight. Gruchet's framework pre-emptively confronts this issue by emphasizing ethical reciprocity: the pilot must remain an active participant, not a subject of monitoring.

The ethical dimension extends to algorithmic accountability. Machine-learning models used for cognitive classification must be auditable and explainable. A pilot should have the right to know not only what the system inferred but why. This interpretability bridges the gap between human cognitive models and artificial ones, ensuring that collaboration remains symmetrical and fair.

The ultimate question raised by cognition-aware CPS is philosophical: what remains of human identity in a cockpit that anticipates, interprets, and even compensates for our cognitive states? Gruchet's answer, implicit across his works, is that the human does not vanish, it evolves. The pilot becomes a meta-controller, supervising not machinery but intelligence itself. The essence of airmanship shifts from manual dexterity to cognitive

command, the ability to understand, calibrate, and co-evolve with adaptive systems.

This evolution mirrors the broader trajectory of technology: from tool use to symbiosis. In early aviation, instruments extended human senses; in the cyber-physical cockpit, systems extend human cognition. Safety, in this paradigm, is no longer a static compliance goal but an emergent property of cooperative intelligence. The pilot's expertise is amplified, not replaced, by AI; and the machine's reliability is humanized by cognitive empathy.

The integration of AI, neurotechnology, and CPS ultimately converges on a single principle: resilient intelligence. In complex socio-technical systems like aviation, failure rarely arises from a single fault; it emerges from the misalignment of human and machine expectations. Adaptive, cognition-aware architectures correct this misalignment continuously, ensuring that perception, decision, and action remain synchronized across all layers of the system.

Gruchet's work thus delineates the blueprint for aviation's next century. By embedding awareness into every component of flight, he reframes safety as a dynamic, evolving property. The cockpit of the future will not merely react to commands; it will perceive intentions, anticipate fatigue, and adapt its behavior to sustain equilibrium. Within this living network of cyber-physical and neuroadaptive intelligence, flight safety becomes not an endpoint but a continuous conversation between human and machine – a conversation that defines the essence of intelligent aviation.

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WATER PURIFICATION FROM RADIOACTIVE ISOTOPES AND HEAVY METALS. (Water purification from radioactive isotopes and heavy metal ions using biomass derived from algae)

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Abstract

This study presents a method for water purification from radioactive isotopes and heavy metal ions using biomass derived from granulated dried algae without the use of chemical reagents. It has been established that dried algal biomass exhibits pronounced ion-exchange properties, enabling the effective adsorption of heavy metal ions and radioactive isotopes. The purification process is carried out by passing water through a volume of biomass, where ion exchange occurs during the contact time, resulting in the removal of contaminating components. Experimental results and industrial application of treatment systems at nuclear facilities have demonstrated that the purification level can reach residual concentrations as low as 0.000001 mg/L, exceeding current environmental standards.

Keywords: *Heavy metal ions; Radioactive isotopes; Biomass derived from marine algae; Granulated dried algae; Radioactive isotope ions; Ion-exchange capacity; Ion-exchange reactions for the adsorption of radioactive isotope ions*

Ion-Exchange Nature of Purification

As demonstrated in practice, dried algal biomass of the OZOLA type exhibits ion-exchange properties, enabling the adsorption of heavy metal ions and radioactive isotope ions. For effective purification, water must pass through a volume of biomass, where ion exchange occurs during the contact time, resulting in the uptake of radioactive isotope ions and associated heavy metal ions by the biomass. Tests and industrial operation of water treatment systems at nuclear facilities have shown that, when using OZOLA, purification levels can be reduced to residual concentrations as low as 0.000001 mg/L, exceeding the requirements of current environmental standards.

Modular Water Purification System Design

The modular purification system is designed as a column or a set of columns, each consisting of standardized segments. Typically, a column may include one, two, or three segments interconnected by a special band made of nylon and polyvinyl chloride,

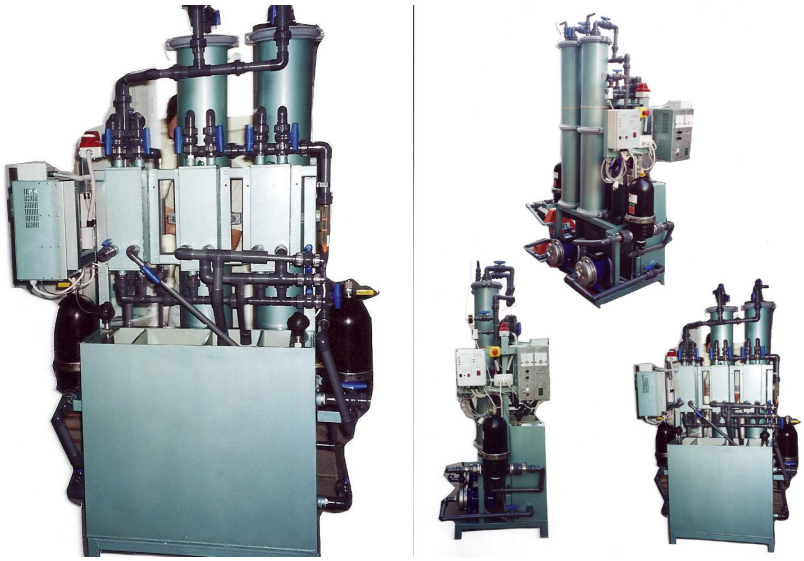
equipped with a silicone rubber sealing element. Assembly or disassembly of the segments requires no more than one minute per connection. Each segment accommodates up to three ion-exchange cartridges. Each ion-exchange cartridge consists of a knitted sleeve made of polyester fibers, filled with OZOLA.

Figure 1. *Water purification from radioactive isotopes and heavy metal ions using biomass derived from marine algae*

The ion-exchange cartridges are designed for single use. The knitted polyester sleeves are mass-produced, with a unit cost not exceeding 5 USD. The columns and associated piping are assembled and installed on a dedicated platform that includes pumps, self-cleaning mechanical filters, and monitoring and control instruments. The cost of a single modular purification system with a capacity of 1 cubic meter per hour – comprising three columns (each consisting of three segments), a pump, a cascade of two inlet mechanical filters, and a cascade of two automatic outlet mechanical filters – is approximately 35,000 USD. The cost of OZOLA for one ion-exchange cartridge is approximately 50 USD.

Figure 2.

Figure 3.



Waste Management of Purification Residues Spent ion-exchange cartridges may be disposed of using several methods. The first method involves incineration under vacuum conditions, followed by encapsulation of the resulting ash in a specialized con-

crete mini-sarcophagus. The second method involves capsule compaction and sealing with lead-containing rubber, followed by placement in specialized containers and storage in decommissioned шахты (mines).

Use of Module Housings For Encapsulation of Spent Material

One of the disposal options is the encapsulation of used segments without disassembly or removal of ion-exchange cartridges. The segments are subsequently stored in decommissioned mines.

Polyester Knit Material as a Component of Ion-Exchange Cartridges

Polyester knit material is used in the form of a sleeve with a high degree of elasticity. Such sleeves are mass-produced and can be supplied in any required quantities.

Challenges in Water Quality Monitoring Using Existing Technologies

All existing technologies for monitoring water quality containing radioactive isotopes and materials in combination with heavy metals require direct contact with water samples, posing risks to both operators and equipment, as elevated radiation levels negatively affect measurement accuracy. Continuous real-time monitoring is not feasible with existing methods. Measurement instruments operating in environments with elevated radiation levels require specialized shielding, which increases cost and reduces reliability. There are no available technologies for rapid, localized monitoring that provide the required level of measurement accuracy. The lack of real-time data on water conditions prevents timely decision-making, which may lead to emergency situations involving complex and high-value equipment.

Innovative Nano-Metrology for Application in Water and Liquid Purification Systems From Radioactive Isotopes Characteristics of the Proposed Application

The proposed solution is a resonant sensor system comprising a power supply unit, signal amplifier, signal converter, and a transmission device for sensor data. The sensor has a ring-shaped design and is installed on control sections of both inlet and outlet pipelines of the water purification system. The estimated cost of a sensor designed for water quality monitoring, including all peripheral components, is approximately 35,000 USD. The estimated cost of a sensor designed for use in level measurement systems is approximately 1,450 USD. Adaptation of the proposed device for measuring concentrations of various components in water or aqueous solutions requires minimal time. Technologically, this involves repeating calibration procedures based on determining optimal resonance parameters characteristic of metal ions or chemical compounds present in the solution. The process takes into account the overall condition of the solution, the proportion of its components, and the chemical background – specifically, the concentrations of stable components that do not change over time and do not influence the measured parameters. A calibration methodology for the resonant circuit has already been developed and tested on a prototype. Test results have been positive and demonstrated the feasibility of adjusting resonance parameters as required, including in automatic operating modes. For sequential measurement of different components within a solution, the signal generated by the sensor is continuously modified according to the optimal resonance parameters corresponding to each component. This enables a single device to monitor concentrations of multiple components sequentially, with automatic adaptation of the resonant circuit to the optimal resonance conditions specific to each component. All such adaptive operations are incorporated into the design of the device's control processors and have been successfully validated during testing.

Market Size The estimated number of sensors required for water quality monitoring in nuclear reactors and nuclear power systems at nuclear power plants exceeds 15,000 units, due to the relatively low capacity of purification systems and the requirement of at least two sensors per system. The estimated total cost of these sensors is approximately 52,500,000 USD. The cost of installation, spare parts supply, and main-

tenance services is estimated at 35% of the sensor cost, amounting to approximately 18,200,000 USD annually. The total estimated market size for monitoring applications is approximately 70,700,000 USD. The estimated number of level sensors for such facilities and industrial applications is approximately 50,000 units. The estimated cost of level sensors is approximately 72,500,000 USD. The total projected market size for sensor applications – including both radioactive water quality monitoring and level sensors operating under radiation conditions – is approximately 143,200,000 USD.

Figure 4.

Selective Measurement of Component Concentrations in Water and Aqueous Solutions

In simplified terms, the selective measurement and monitoring of concentrations of metal salts and other elements dissolved in water can be explained as follows. Water possesses an exceptionally high dielectric constant, which is a consequence of the significant dipole moment of water molecules. Accordingly, the integral polarization variable in an alternating electric field is strongly influenced both by the concentration of nonpolar impurity molecules and by molecules with dipole moments differing from that of water. This difference forms the basis of the resonant method for selective measurement of impurity concentrations in water or aqueous solutions. When water is introduced into an oscillatory circuit, it determines the position of its characteristic resonance line. Each impurity introduced into the water or aqueous solution within this circuit shifts the resonance and the corresponding resonance line. It follows that different impurities, depending on their concentration, will cause distinct resonance shifts. The existence of a set of such dependencies, each corresponding to a specific metal or element, enables selective determination of the magnitude of the resonance shift and, consequently, the concentration of each impurity in water or an aqueous solution. This set of dependencies is established through chemical calibration using conventional analytical methods. For liquids that are not aqueous solutions, the methodology and principles of selective concentration measurement are similar, with the distinction that one of the components of the solution or liquid – having the highest dipole moment – is used as the reference baseline for comparison during measurement.

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PROCESSES OF DYNAMIC ACTIVATION OF LIQUID FUEL. (Sequential Dynamic Homogenization in a Modern Gasoline Engine; Potential Applications of the Dynamic Homogenization Process; Thermodynamic Effects of Using Homogenized Fuel Produced by a Dynamic Homogenization Device)

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Abstract:

Liquid hydrocarbon fuels and fuel compositions based on them tend to lose structural homogeneity during storage, leading to the formation of sediment and agglomerates that accumulate in storage tanks. This problem becomes particularly significant for synthetic fuels produced through the recycling of plastic waste and used automobile tires, as such fuels may contain atypical contaminants, including compounds such as formaldehyde. Ensuring homogeneous fuel composition is therefore essential for efficient and stable combustion processes. This paper presents an innovative technology for the dynamic homogenization of liquid fuels and fuel mixtures using a specialized device integrated directly into the fuel pipeline. The proposed system consists of an accelerating hydrodynamic section, a vortex-generation module, and a turbulence amplification unit connected to the inlet of the high-pressure pump of an internal combustion engine. The technology implements a sequential dynamic homogenization process in which controlled turbulence and vortex flow formation significantly reduce the particle size within the fuel mixture to below one micron. As a result, the fuel acquires properties comparable to a nanoscale homogenized emulsion, which improves fuel stability and combustion efficiency. The proposed principle can be applied not only to internal combustion engines but also to fuel supply systems in boilers, burners, turbines, and other thermodynamic equipment, where maintaining fuel homogeneity contributes to improved operational performance and energy efficiency.

Keywords: *Liquid fuel; Dynamic activation of liquid fuel; Sequential dynamic homogenization process; Thermodynamic effect of using homogenized fuel; Fuel compositions based on liquid hydrocarbon fuels; Homogenization process using an innovative dynamic homogenization device performing homogenization directly within the pipeline through which the fuel or fuel mixture flows; Transformation of the homogenized liquid fuel or fuel mixture flow into a hydrodynamic vortex tube*

The necessity of the homogenization process

Any type of liquid hydrocarbon fuel, and especially fuel compositions based on liquid hydrocarbons, tends to lose its homogeneity during storage. As a result, agglomerates and sediments form, primarily at the bottom of tanks in which the fuel or fuel mixture is stored.

Ensuring homogeneity becomes even more problematic for various types of synthetic liquid fuels, particularly those obtained through the recycling of waste plastics or used automobile tires. Such fuels often contain a wide range of additional and atypical contaminants for conventional fuel compositions, for example formaldehyde. This further increases the necessity for homogenization, at least prior to fuel injection into the combustion chamber or during the combustion process itself.

The elimination of this heterogeneity can be achieved most efficiently 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 mixture flows.

Dynamic homogenization process

First, it is necessary to briefly describe the properties, operational characteristics, and technological novelty of the proposed solution.

The device for dynamic homogenization of liquid fuel and fuel mixtures consists of an accelerating hydrodynamic section transitioning into a second coaxial hydrodynamic section equipped with an integrated vortex generator. This section further transitions into a hydrodynamic turbulence amplification module connected to the inlet of the high-pressure pump of an internal combustion engine.

Within the dynamic homogenization device, the liquid fuel or fuel mixture is divided into two streams. The first stream (approximately 60% of the total flow) enters the accelerating hydrodynamic section under a pressure of at least 3 bar (45 psi). Acceleration occurs under the influence of system elements that initiate the formation of coaxial Bernoulli-type effects. The second stream (approximately 40% of the total flow) enters the second hydrodynamic section, which is arranged coaxially with the first section, also under a pressure of at least 3 bar (45 psi).

Inside the device, a dynamic sequential homogenization of the liquid fuel or fuel mixture occurs. During the first stage, homogenization is achieved through controlled turbulence within the pipeline. Such a process is absent in all currently known homogenization devices and technologies, representing one of the principal elements of technological novelty. This novelty is confirmed in the core intellectual property documents of the company that developed and owns the technology.

After this stage, the homogenized flow of liquid fuel or fuel mixture is transformed into a hydrodynamic vortex tube due to the action of the integrated vortex generator and is directed toward the high-pressure pump of a diesel engine or any other internal combustion engine operating at pressures of approximately 2000–3000 bar (29,000–43,500 psi). At this stage, the second phase of dynamic homogenization occurs within the flow. As a result, the particle size in the homogenized stream is reduced to less than one micron. According to the key parameters of the flow, the fuel effectively becomes a homogenized liquid equivalent in properties to a nanoscale emulsion.

A similar operational principle can be applied in fuel supply systems of boilers, burners, turbines, and other thermodynamic equipment.

The homogenization process takes place in less than one second and does not disturb the natural interrelations within the homogenized liquid fuel or fuel mixture.

The process occurs at a stable temperature or, under certain operating ratios, may even lead to a reduction in the temperature of the combustible liquid or fuel mixture.

The entire dynamic homogenization process is achieved through the creation of specific turbulent hydrodynamic conditions in the fuel or fuel mixture flow, without disrupting the chemical and physical equilibrium among its components.

Positive differences of the dynamic homogenization process compared with existing technologies:

- Existing technologies do not include a stage of dynamic homogenization based on the level of turbulence, which means that current technologies cannot perform

the homogenization process directly within the fuel pipeline of an internal combustion engine;

- The second stage of the homogenization process in the proposed technology takes place under pressure that is at least twice as high as that required for homogenization at the nanoscale particle level;
- The particle (globule) sizes in the liquid fuel or fuel mixture homogenized using the proposed technology are uniform and fall within the range of 70–120 nanometers, and they do not tend to agglomerate. In existing technologies, the size distribution varies widely – from the smallest to the largest particles – by more than an order of magnitude, typically from 0.2 to 2 microns;
- All processes of dynamic homogenization can be performed directly in the fuel pipeline of an internal combustion engine, for example between the fuel pump and the high-pressure pump, and do not require any special modifications to the engine design. The same principle applies to other types of thermodynamic equipment;
- During the dynamic homogenization process, the temperature of the homogenized liquid fuel or fuel mixture does not increase;
- The dynamic homogenization device also allows, during the homogenization process, the simultaneous introduction of additional components into the homogenized liquid fuel or fuel mixture, such as water, methanol, ethanol, or synthetic kerosene;
- The dynamic homogenization device has compact dimensions and is more convenient to operate than known devices. It provides optimal conditions for installation and maintenance;
- The cost of the dynamic homogenization device for liquid fuels and fuel mixtures is significantly lower than that of existing equipment designed for similar purposes;
- The device can also be used to perform technological homogenization before introducing the fuel or fuel mixture flow into industrial processing equipment used for the production of other hydrocarbon products.

As can be seen from the presented photographs, the dimensions of the device are very small relative to its performance capacity (the images show devices with a capacity of 1,000 liters per hour).

Original dynamic homogenization device

An original device for the dynamic homogenization of liquid fuels and fuel mixtures has been developed, manufactured, and repeatedly tested.

All components and parts of the device are manufactured using standard CNC machines, without the need for special technologies or specialized cutting tools.

Stainless steel is used as the primary construction material, allowing the device and systems based on it to be installed in corrosive environments, for example on marine vessels.

Figure 1.

The device is extremely compact and has dimensions that allow it to be integrated into virtually any internal combustion engine, including both stationary engines (for example, marine engines) and engines installed in transport vehicles (such as automobiles of all types).

The device does not require any additional elements or auxiliary components for operation and can be installed directly in the fuel pipeline of an internal combustion engine, specifically between the fuel pump and the high-pressure pump.

All inlet and outlet connection interfaces of the device are standardized. Installation of the device on an internal combustion engine does not require special preparation, tools, or equipment.

The device contains no moving parts and can be manufactured in any required dimensional scale. It can be produced using stan-

dard industrial equipment with numerical control (CNC). The manufacturing, assembly, and quality control processes do not require special technologies, materials, or specialized tools.

Thermodynamic effect of using homogenized fuel (produced using the dynamic homogenization device)

After homogenization, the fuel burns uniformly, and no local zones with larger dispersed fractions are formed within the fuel volume after injection.

As a result, the combustion process proceeds 35–40% faster, and efficient heat extraction increases proportionally. These results have been confirmed in more than 300 testing cycles on a modern production diesel engine with a 2.5-liter displacement.

The homogenization technology operates equally effectively in engines with standard configurations as well as in engines equipped with exhaust gas recirculation (EGR) systems.

In the event of unauthorized water ingress into the fuel tank, dynamic homogenization – within several milliseconds before the fuel reaches the high-pressure pump – ensures the dynamic formation of a micro-emulsion, completely eliminating any harmful effects of water contained in the fuel emulsion on engine operation. These results have been confirmed in more than 60 test cycles on a modern production diesel engine with a 2.5-liter displacement.

The resulting micro-emulsion, while maintaining the effective power output of the engine, significantly reduces the concentration of soot in exhaust gases (reduction of up to 97%) and decreases nitrogen oxide emissions (reduction of up to 35%). It also shortens the full combustion cycle and accelerates the heat extraction process. These results have been confirmed in more than 300 full reversible testing cycles on a modern production diesel engine with a 2.5-liter displacement.

Application of the homogenization system

The application of the homogenization system additionally makes it possible to obtain, at 35–45% lower pressure, the same spray dispersion that is typically achieved at injection pressures of 1600–2000 bar.

This phenomenon allows a reduction in the power consumption required for the operation of the high-pressure pump. As an example, the same effect can be considered a potential additional efficiency factor for turbines and turbo-generators, where injection pressures are typically 30 bar or higher.

Environmental effect of using homogenized fuel.

The application of the dynamic homogenization device in the fuel systems of internal combustion engines makes it possible to significantly reduce the toxicity of exhaust gases and may allow previously manufactured vehicles, including those that have been in operation for many years, to meet modern environmental standards.

Sequential dynamic homogenization process in a modern diesel engine.

In a modern diesel engine, the device for dynamic homogenization of fuel or fuel mixtures is installed in the fuel line after the fuel pump and before the high-pressure pump.

The fuel flow leaving the fuel pump is divided into two streams. The first stream, accounting for 60% of the total fuel flow, is directed into the central axial inlet of the dynamic homogenization device. The second stream, accounting for 40% of the total fuel flow, is introduced into an integrated inlet system consisting of four radial channels.

After homogenization, the fuel burns uniformly, and no local zones with larger dispersed fractions are formed within the injected fuel volume.

As a result, the combustion process proceeds 35–40% faster, and the efficiency of heat extraction increases proportionally. These results have been confirmed in more than 60 testing cycles on a modern production diesel engine with a 2.5-liter displacement.

The homogenization technology operates equally effectively in engines with standard configurations as well as in engines equipped with exhaust gas recirculation (EGR) systems.

Sequential dynamic homogenization process in a modern gasoline engine.

In a modern gasoline engine, the device for dynamic homogenization of fuel and fuel mixtures is installed in the fuel line after the fuel pump and before the high-pressure pump.

The fuel flow after the fuel pump is also divided into two streams. One stream, accounting for 60% of the total fuel flow, is directed to the central axial inlet of the dynamic homogenization device, while the second stream, accounting for 40% of the total flow, enters the device through an integrated inlet consisting of four radial channels.

The homogenization technology functions equally effectively in engines with standard configurations and in engines equipped with exhaust gas recirculation systems.

Application of the dynamic homogenization process in internal combustion engines using a mixture of ethanol and gasoline as fuel.

Ethanol, even of high quality, contains a certain amount of water.

Before mixing (for example) with gasoline, ethanol is a relatively stable substance and the separation of water and alcohol does not occur. However, a mixture of ethanol and gasoline is not completely stable and, under certain conditions (for example at low temperatures), water may separate from the gasoline–ethanol mixture.

If a dynamic homogenization device is integrated into the engine system, the water that has separated in the fuel tank from the main hydrocarbon fraction of the fuel mixture is dynamically mixed within the device with the hydrocarbon fractions, transforming the resulting mixture into a micro- or nanoscale emulsion.

The combustion of such an emulsion typically occurs in a stable thermodynamic regime, without detonation and with reduced levels of soot and nitrogen oxides in the exhaust gases.

Application of the dynamic homogenization process in internal combustion engines using a mixture of methanol and gasoline as fuel.

Methanol, even of ordinary quality, practically does not contain water.

Before mixing (for example) with gasoline, methanol is a relatively stable substance and, after mixing, it generally does not separate from gasoline.

Nevertheless, the methanol–gasoline mixture is not completely stable and, under certain conditions (for example at low temperatures), it tends to form agglomerates or clots.

The combustion of homogenized fuel in such systems generally occurs in a stable thermodynamic regime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

Application of the dynamic homogenization process in internal combustion engines using gasoline mixed with biofuel compositions

In such thermodynamic systems, the fuel consists of gasoline combined with heavier biological fuels and various viscous combustible biological materials. In these composite fuels, the formation of agglomerates occurs more intensively.

If a dynamic homogenization device is introduced into the thermodynamic system, agglomerates that have formed in the fuel tanks – consisting primarily of the hydrocarbon fraction of the fuel mixture – are dynamically mixed in the device with the remaining hydrocarbon fractions. As a result, these agglomerates are transformed into a uniform system of micro- or nanoscale particles.

The combustion of the homogenized fuel generally occurs in a stable thermodynamic regime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

Application of the dynamic homogenization process in fuel supply systems for burners, boilers, turbines, and other thermodynamic equipment.

In such thermodynamic systems, the fuels used typically include heavier diesel fuels and various types of fuel oil, where the formation of agglomerates from heavier fractions with high viscosity occurs more intensively.

If a dynamic homogenization device is integrated into the fuel supply and injection system of the combustion chamber, agglomerates that form in the fuel tanks – composed of the main hydrocarbon fraction of the fuel mixture – are dynamically mixed within the device with the remaining hydrocarbon fractions. This process transforms the agglomerates into micro- or nanoscale particles.

The combustion of homogenized fuel typically occurs in a stable thermodynamic regime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

In certain cases and under specific conditions, significant fuel savings may also be achieved.

Potential application of the dynamic homogenization process in marine engines and diesel generators.

In such thermodynamic systems, heavier diesel fuels and various types of fuel oil are typically used as fuel. In these types of fuels, the formation of agglomerates occurs more intensively due to the presence of heavier fractions.

If a dynamic homogenization device is integrated into the fuel system of a marine engine or a diesel generator, agglomerates that may form in the fuel tanks under certain conditions – consisting mainly of the primary hydrocarbon fraction of the fuel mixture – are dynamically mixed within the device with the remaining hydrocarbon fractions. As a result, these agglomerates are transformed into micro- or nanoscale particles.

The combustion of homogenized fuel typically occurs in a stable thermodynamic regime, without detonation and with reduced concentrations of soot and nitrogen oxides in the exhaust gases.

Potential application of the dynamic homogenization process in propulsion systems of aircraft

In recent years, there have been reports regarding the experimental use of biofuels and fuel mixtures containing biological components in aircraft engines. It is known that fuel mixtures containing biofuel components tend to form agglomerates during storage and operation.

Dynamic homogenization of such fuels prior to injection into the combustion chamber can significantly increase the reliability of aircraft engines and may create new opportunities for the practical use of composite fuel formulations in aviation propulsion systems.

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THERMODYNAMIC APPARATUS WITH AN INTEGRATED DYNAMIC MIXING SYSTEM. (Thermodynamic apparatus with an integrated dynamic system for real-time mixing and homogenization of fuel components using elements of artificial intelligence and artificial neural networks)

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Abstract

Any type of liquid hydrocarbon fuel, and especially fuel compositions based on liquid hydrocarbon fuels, tends to lose its homogeneity during storage. As a result, agglomerates and sediment formations occur, predominantly at the bottom of storage tanks containing the fuel or fuel mixture.

The elimination of such heterogeneity can be most efficiently achieved through the innovative homogenization process developed by Kristina Bessarabenko, implemented by means of an innovative dynamic homogenization device that performs homogenization directly within the pipeline through which the fuel or fuel mixture flows.

The homogenization process is carried out at a stable temperature or, under certain ratios and operational conditions, with a decrease in the temperature of the combustible liquid or fuel mixture.

The entire dynamic homogenization process is achieved by generating specific turbulent hydrodynamic conditions within the flow of liquid fuel or fuel mixture, without disrupting the chemical and physical equilibrium among its components.

Keywords: *Thermodynamic apparatus; integrated dynamic mixing system; homogenization process; hydrodynamic vortex tube; homogenization based on turbulence level; vortex generator; accelerating hydrodynamic section; coaxial Bernoulli effect*

Dynamic Fuel Homogenization Device for Internal Combustion Engines

Necessity of the Homogenization Process

Any type of liquid hydrocarbon fuel, and especially fuel compositions based on liquid hydrocarbons, loses its homogeneity during storage. As a result, agglomerates and deposits are formed, predominantly at the bottom of storage tanks containing the fuel or fuel mixture.

The elimination of this heterogeneity can be achieved most efficiently and conveniently by applying a homogenization process using an innovative dynamic homogenization device that performs the homogenization directly within the pipeline through which the fuel or fuel mixture flows.

Dynamic Homogenization Process

First, a brief overview of the proposed technology developed by Kristina Bessarabenko, including its distinctive features, novelty, and degree of innovation:

The device for dynamic homogenization of liquid fuel and fuel mixtures consists of an accelerating hydrodynamic section transitioning into a second, coaxially aligned hydrodynamic section with an integrated vortex generator, which in turn transitions into a hydrodynamic turbulence amplification unit connected to the inlet of the high-pressure pump of an internal combustion engine.

Within the dynamic homogenization device, the entire flow of liquid fuel or fuel mixture is divided into two streams:

- The first stream (60% of the total flow), under a pressure of 3 bar (45 psi), is directed into the accelerating hydrodynamic section, where acceleration is achieved through system elements that initiate the formation of coaxial Bernoulli effects;
- The second stream (40% of the total flow), also under a pressure of 3 bar (45 psi), is directed into the second hydrodynamic section, coaxial with the first.

The device performs a dynamic process of sequential homogenization of the liquid fuel or fuel mixture flow.

At the first stage, homogenization is carried out based on the turbulence level within the pipeline. Such a process is not implemented in any known homogenization devices or technologies and constitutes one of the core elements of the technological novelty, as confirmed by the foundational intellectual property documentation of the developer and technology owner.

Subsequently, the homogenized flow of liquid fuel or fuel mixture is transformed into a hydrodynamic vortex tube (due to the integrated vortex generator) and directed to the high-pressure pump of the internal combustion engine (operating at 2,000 to 3,000 bar, or 29,000–43,500 psi).

At this stage, a second phase of dynamic in-flow homogenization occurs, resulting in the reduction of particle size within the homogenized stream to below one micron. According to the key flow parameters, the medium is thereby converted into a homogenized liquid equivalent in properties to a nanoscale emulsion.

The homogenization process takes less than one second and does not disrupt any natural physicochemical interrelationships within the homogenized liquid fuel or fuel mixture.

The homogenization process is carried out at a stable temperature or, under certain ratios and operating conditions, with a decrease in the temperature of the combustible liquid or fuel mixture.

The entire dynamic homogenization process is achieved through the creation of specific turbulent hydrodynamic conditions within the flow of liquid fuel or fuel mixture, without disturbing the chemical and physical equilibrium among its components.

It should be noted that in advanced innovative projects – not only in fuel blending and dynamic homogenization processes, but also in analogous processes of mixing and homogenization, for example, of liquid food components – the above-mentioned positive effects manifest even more distinctly.

Several years ago, Kristina Bessarabenko was among the first to successfully initiate work in this direction. She is a multidisciplinary specialist and a well-known international initiator of startup projects in which dynamic homogenization processes constitute the technological foundation for pro-

ducing new environmentally friendly products with fundamentally enhanced performance characteristics.

Based on the unique qualitative indicators of homogenized tea-and-milk blends invented by Kristina Bessarabenko, the implementation of dynamic homogenization methods in their production processes enabled these innovative products to enter global markets within a remarkably short period of time.

Due to the exceptional level of technological refinement of the group technology developed by Kristina Bessarabenko, a number of additional advantages of the process have been achieved.

Advantages of the Dynamic Homogenization Process Developed by Kristina Bessarabenko Compared to Existing Technologies

- Existing technologies do not include a stage of dynamic homogenization based on turbulence level; therefore, they do not enable homogenization to be carried out directly within the fuel pipeline of an internal combustion engine;
- The second stage of homogenization in the proposed process is performed under pressure at least twice as high as that required for homogenization at the nanoscale particle level;
- The particle (globule) sizes in the liquid fuel or fuel mixture homogenized according to the proposed technology are uniform, ranging within 70–120 nanometers, and exhibit no tendency toward agglomeration. In contrast, existing technologies demonstrate a particle size distribution exceeding a tenfold range – from approximately 0.2 to 2 microns;
- All stages of dynamic homogenization can be carried out directly within the fuel pipeline of an internal combustion engine, for example, between the fuel pump and the high-pressure pump, and do not require any special modifications to the engine design;
- During the dynamic homogenization process, the temperature of the homogenized liquid fuel or fuel mixture does not increase;
- The dynamic homogenization device enables the simultaneous introduction of additional components into the homogenized liquid fuel or fuel mixture (for example, water, methanol, or ethanol) during the homogenization process;
- The dynamic homogenization device has compact dimensions, is more convenient in operation than known analogues, and provides optimal conditions for installation and maintenance;
- The dynamic homogenization device for liquid fuels and fuel mixtures is significantly more cost-effective than existing equipment of similar purpose;
- The device may also be used for technological homogenization prior to introducing the fuel or fuel mixture stream into technological equipment for the production of other hydrocarbon-based products.

Original Device for Dynamic Homogenization

An original device for the dynamic homogenization of liquid fuels and fuel mixtures has been developed, manufactured, and repeatedly tested.

The device is extremely compact, with dimensions allowing its integration into virtually any internal combustion engine, including stationary engines (for example, marine engines) as well as engines installed in transport vehicles (such as automobiles of all types).

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 – after the fuel pump and before the high-pressure pump.

All inlet and outlet connection elements are standardized. Installation of the device on an internal combustion engine does not require special preparation, tools, or equipment.

The device contains no moving parts and may be manufactured in any required dimensional scale.

It can be produced using standard serial production equipment with numerical control (CNC). No special technologies, materials, or tools are required for manufacturing, assembly, or quality control.

Thermodynamic Effect of Using Homogenized Fuel

(Obtained by Means of the Dynamic Homogenization Device)

After homogenization, the fuel combusts uniformly; following injection, no local zones with larger dispersion fractions are formed within its volume.

As a result, the combustion process proceeds 35–40% faster, and effective heat release is accelerated in the same proportion. These results have been confirmed in more than 60 test cycles conducted on a modern production diesel engine with a displacement of 2.5 liters.

The homogenization technology operates equally effectively in standard engine configurations as well as in engines equipped with exhaust gas recirculation (EGR) systems.

In the event of accidental water ingress into the fuel tank, dynamic homogenization – within milliseconds prior to the fuel entering the high-pressure pump – ensures the formation of a stable micro-emulsion and completely eliminates any harmful effects of water contained in the fuel emulsion on engine operation. These results have been confirmed in more than 60 test cycles on a modern production diesel engine with a displacement of 2.5 liters.

The resulting micro-emulsion, while maintaining effective engine power output, significantly reduces soot concentration in exhaust gases (reduction of 97%) and nitrogen oxide (NO_x) concentration (reduction of 12%), shortens the complete combustion cycle duration, and accelerates heat release. These results have been confirmed in more than 60 full reversible test cycles on a modern production diesel engine with a displacement of 2.5 liters.

Environmental Effect of Using Homogenized Fuel

The application of a dynamic liquid fuel homogenization device within the fuel system of internal combustion engines significantly reduces exhaust gas toxicity and may enable compliance with environmental standards in previously manufactured vehicles, including those that have been in long-term operation.

Sequential Dynamic Homogenization Process in a Modern Diesel Engine

The dynamic fuel and fuel – air mixture homogenization device in a modern diesel engine is installed in the fuel line downstream of the fuel pump and upstream of the high-pressure pump.

The fuel flow after the fuel pump is divided into two streams. One stream, accounting for 60% of the total fuel flow, is directed to the central axial inlet of the dynamic homogenization device. The second stream, accounting for 40% of the total fuel flow, is introduced through an integrated inlet consisting of four radial channels.

After homogenization, the fuel combusts uniformly. Following injection, no localized zones containing larger dispersed fractions are formed within the fuel volume.

As a result, the combustion process occurs 35–40% faster, and effective heat extraction is accelerated proportionally. These results have been confirmed through more than 60 test cycles conducted on a modern production diesel engine with a displacement of 2.5 liters.

The homogenization technology operates equally effectively in engines with standard configurations and in engines equipped with exhaust gas recirculation (EGR) systems.

Sequential Dynamic Homogenization Process in a Modern Gasoline Engine

In a modern gasoline engine, the dynamic fuel and fuel–air mixture homogenization device is installed in the fuel line downstream of the fuel pump and upstream of the high-pressure pump.

The fuel flow after the fuel pump is divided into two streams. One stream, accounting for 60% of the total fuel flow, is directed to the central axial inlet of the dynamic homogenization device. The second stream, accounting for 40% of the total fuel flow, is introduced through an integrated inlet consisting of four radial channels.

The homogenization technology operates equally effectively in engines with standard configurations and in engines equipped with exhaust gas recirculation (EGR) systems.

Application of the Dynamic Homogenization Process in Internal Combustion Engines Using an Ethanol – Gasoline Fuel Blend

Ethanol, even of high purity, contains a certain amount of water.

Prior to blending (for example, with gasoline), ethanol is a sufficiently stable substance in which phase separation between water and alcohol does not occur.

However, an ethanol–gasoline mixture is not completely stable. Under certain conditions (for example, at reduced temperatures), water may separate from the gasoline – ethanol mixture.

If a dynamic homogenization device is incorporated into the engine fuel system, the water that has separated in the fuel tank from the primary hydrocarbon fraction of the fuel blend may, under specific conditions, be dynamically re-mixed with the hydrocarbon fractions within the homogenization device. As a result, the mixture is converted into a micro- or nano-scale emulsion.

Combustion of such an emulsion generally occurs in a stable thermodynamic regime, without detonation, and with reduced levels of soot and nitrogen oxides (NO_x) in the exhaust gases.

Application of the Dynamic Homogenization Process in Internal Combustion Engines Using a Methanol–Gasoline Fuel Blend

Methanol, even of standard commercial grade, contains virtually no water.

Prior to blending (for example, with gasoline), methanol is a sufficiently stable substance and, after mixing, does not significantly separate from gasoline.

Nevertheless, the methanol – gasoline mixture is not completely stable and, under certain conditions (for example, at reduced temperatures), may exhibit a tendency toward agglomeration or phase irregularities.

Combustion of homogenized fuel generally occurs in a stable thermodynamic regime, without detonation, and with reduced soot and nitrogen oxide (NO_x) emissions in the exhaust gases.

Application of the Dynamic Homogenization Process in Internal Combustion Engines Using Gasoline Blended with Biological Fuel Compositions or Organic Fuel Components

In such thermodynamic systems, the fuel consists of a mixture containing gasoline along with heavier biofuels and various types of viscous combustible biological materials. In these composite fuels, agglomeration and the formation of fuel clusters occur more intensively.

If a dynamic homogenization device is incorporated into the thermodynamic system, fuel clusters that have formed in the fuel tanks – consisting primarily of the main hydrocarbon fraction of the fuel blend – are dynamically re-mixed within the device with the remaining hydrocarbon fractions. This process converts the agglomerated mixture into a homogeneous system composed of micro- or nano-scale particles.

Combustion of the homogenized fuel generally proceeds in a stable thermodynamic regime, without detonation, and with reduced soot and nitrogen oxide (NO_x) emissions in the exhaust gases.

Application of the Dynamic Homogenization Process in Fuel Supply Systems for Boilers, Turbines, and Other Thermodynamic Devices

In the above-mentioned thermodynamic systems, heavier diesel fuels and various types of fuel oil are typically used as fuel. In such fuels, the formation of agglomerates consisting of heavier, high-viscosity fractions occurs more intensively.

If a dynamic homogenization device is incorporated into the fuel supply and injection system of the combustion chamber, fuel agglomerates that have formed under certain conditions in the fuel tanks – primarily consisting of the main hydrocarbon fraction of the fuel mixture – are dynamically re-mixed within the device with the remaining hydrocarbon fractions. As a result, the agglomerated structures are transformed into micro- or nano-scale particles.

Combustion of the homogenized fuel generally proceeds in a stable thermodynamic regime, without detonation, and with reduced

soot and nitrogen oxide (NO_x) emissions in the exhaust gases.

In certain cases and under specific operating conditions, significant fuel savings may also be achieved.

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ALGORITHMIC COMPONENT IN INTEGRATED INNOVATIVE PROJECTS. (The Algorithmic Component in Integrated Innovative Projects: A Case Study of the Analysis of the Development of Fuel Mixture Modification Technologies)

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Abstract

Based on the current state of development of a new technological direction related to the creation of efficient thermodynamic technologies for optimizing fuel mixtures of various types, primarily intended for industrial and individual energy applications, it is advisable to apply a step-by-step scheme of sequential actions aimed at forming basic intellectual property objects in the above-mentioned technological areas. This strategic approach makes it possible to minimize the costs of research and development while ensuring maximum protection of technical solutions underlying the invention.

The paper considers an algorithm for integrating local technical solutions, each having the level of an invention, into a single integrated technical solution that provides a complex technological effect. A structural analysis of a group of technical solutions underlying the design of a device for dynamic mixing and activation of fuel mixture components, including a main liquid component, additional liquid components, and an activating gaseous component, has shown that the integrated technical solution in the presented design version includes a number of interrelated local technical solutions that ensure increased efficiency of mixing, activation, and subsequent use of fuel mixtures.

Keywords: *Technical level qualification of the project; Algorithm for integration of local technical solutions; Device for dynamic mixing of heterogeneous fuel mixture components; Processes and technologies with active monitoring of quality aspects of processes and materials; Regenerative electrolytic recirculation system*

Introduction

The algorithmic component in complex innovation projects is considered using the example of analyzing the development of technologies for the modification of fuel mixtures. The qualification of the technical level of a project, as exemplified by the evaluation and qualification of a complex project - a device for dynamic mixing of heterogeneous components of fuel mixtures and their

subsequent activation - has a distinctly expressed algorithmic component.

At the present time, the project is at a stage of readiness corresponding to the manufacturing and completion of the first stage of production testing of an industrial prototype of the product — a device for dynamic mixing of heterogeneous components of fuel mixtures and their subsequent activation.

Figure 1. *Device and its components*

There is one specific feature that must be analyzed in order to ensure the required level of online interaction between all components and structural elements of the system. To enable participation in processes and technologies with active monitoring of qualitative aspects of processes and materials, as well as sufficiently high-speed automatic control and management systems, it is necessary, in addition to devices for dynamic online mixing and homogenization of process fluids in real time, to use high-speed electronic boards whose performance is comparable to that of modern computer motherboards.

For systems that are controlled and managed within standard aerial survey processes, the performance requirements are even more stringent. Such electronic boards include, first of all, the so-called RITM boards manufactured using dimensional selective metal etching technology.

The main distinguishing feature of such boards is that a steel strip made of special steel containing aluminum (38KhMYuA steel) is used as the base carrier material. The thickness of such a strip is only 50 microns, which makes it possible, compared to conventional carriers made of getinax or fiberglass laminate, to significantly reduce the distance between structures on both sides of the board.

Since the manufacturing process of such boards differs significantly from conventional printed circuit boards, it is advisable to consider this specific technology in more detail. The technological stages for manufacturing such boards should be considered taking into account all features and specific differences.

To manufacture such boards, the following operations must be performed:

- preparation of the surface of the steel strip (coil) (instead of steel, a metal strip may be used if it provides the properties and characteristics equivalent to steel grade 38KhMYuA); during surface preparation, it is advisable to use reagent-free technologies and disinfection using water with adjusted acidity and alkalinity levels;
- application of photoresist; production volume plays an important role here, and depending on production scale, different photoresist application methods may be selected; several well-established and similar application methods exist, which also differ depending on the type of photoresist and specific production conditions;
- development of the photoresist; there is experience in using serial conveyor-type photoresist development lines with full recirculation of process solutions and complete regeneration of all consumables, water, and chemical reagents;
- high-speed jet electrochemical nickel plating (2–3 microns thick). This type of electrochemical coating is the subject of a separate invention and is currently under development in electronics and microelectronics manufacturing technologies. The main dis-

tinguishing features of this invention include rotating anodes located in a plane parallel to the metallized surface and containing soluble elements within the working volume in front of the injection plate; an extremely small distance between the anode plane and the cathode (metallized surface); injection of electrolyte through the injection plate of the anode module perpendicular to the metallized surface (cathode). In this configuration, the metallization rate is ten times higher compared to conventional metallization;

- high-speed jet electrochemical copper plating (25–35 microns thick). This type of coating is similar to nickel plating and has the same distinguishing features, but is fundamentally new and requires additional explanation.

It can be stated that this type of coating and its sequential technological processing is, to a certain extent, a technological phenomenon. Since this technological phenomenon forms the main fundamental difference and provides a set of significant advantages of the method, it is necessary to provide an explanation of this phenomenon.

To qualify all distinguishing features of this process, the following definition is proposed:

– A complex technical solution is proposed, representing a combination of technological stages and operations, materials, and tools, including high-speed jet electrochemical deposition — a galvanic process carried out directly in the metallization zone under specific conditions with the following distinguishing features and technological characteristics.

– First of all, a clear definition of the nature of the formed electrolyte flow is required. It is initially defined that the metallization process is carried out in a selectively oriented electrolyte flow, in which the electrolyte is directed and injected onto the metallized surface, while the electrolyte flow rate is strictly controlled in order to eliminate negative edge effects on the cathode (the coated surface).

– It is also defined that the metallization process is carried out in a directed electrolyte flow, with the direction of the electrolyte jets being perpendicular to the metallized surface.

– It is further defined that the metallization process is carried out using a constant regenerative electrolyte recirculation system.

The recirculation system includes:

1. A container with electrolyte having specific operating parameters, such as:

- defined nickel and copper concentration values ensuring maximum efficiency and optimal deposited layer density without edge effects and with uniform thickness across the entire topology of the RITM board;
- defined electrolyte temperature values;
- defined electrolyte acidity or alkalinity values;
- defined electrolyte density values;
- defined electrolyte electrical conductivity values.

It should be particularly noted that due to the advantages of this technology, there is no need to use organic additives or activating materials, which significantly simplifies the electrolyte recirculation processes.

At the present time, the project is at a stage of readiness corresponding to the manufacturing and completion of the first stage of production testing of an industrial prototype of the product — a device for dynamic mixing of heterogeneous components of fuel mixtures and their subsequent activation.

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It should be particularly noted that due to the advantages of this technology, there is no need to use organic additives or activating materials, which significantly simplifies the electrolyte recirculation processes.

- a method for summation of the kinetic energy of liquid and gaseous working media flows during their dynamic mixing in a hermetically sealed volume;
- a system consisting of a method and a device for increasing the turbulence level in a gaseous working agent flow through geometric structural transformation of the flow cross-section and an increase in its linear velocity;
- a method and a device for forming an annular low-pressure zone in a pneumatic pipeline;
- a method and a device for converting a directed liquid flow into a directed aerosol flow;
- a device for separating liquid and gas flows before mixing and combining them after mixing;
- a device for separating liquid and gas flows before mixing and combining them after mixing into a vortex flow;
- a method and a device for forming a double low-pressure zone in a hydraulic pipeline when connected to a pneumatic pipeline;
- a method and a device for connecting hydraulic and pneumatic flows during their dynamic mixing;
- a method and a device for changing the direction of movement of the working agent flow in a pipeline.

All of the listed solutions collectively make it possible to form a number of general technological solutions, which in turn are part of integrated solutions within the specified technology and its application variants.

These solutions include:

- a method and a device for preliminary mixing of liquid fuel components in a fuel pipeline.

The algorithm and logistics of the project development process for integrating a device for dynamic mixing of fuel components into fuel supply systems of thermal equipment, including boilers of all types, are considered. For boiler applications, the device must include a nozzle to ensure a higher level of compatibility with fuel supply systems to the combustion chamber or burner. The development of the nozzle is one of the components of the project. At the same time, the device itself may be presented as a standalone product or as a compact burner. This applies equally to boilers that use diesel fuel as well as boilers that use natural gas as fuel.

All variants and working versions of the device and its application technology may be developed simultaneously in parallel.

For devices intended for dynamic mixing of fuel components in which liquid fuel plays a dominant role, a number of phenomena occur that can be described as technological paradoxes.

The first paradox is that in a pipeline, with the same cross-section, the same initial pressure, and the same initial flow rate of an incompressible liquid component, an annular vacuum zone is formed without additional energy consumption. This zone acts as a boundary between the incompressible liquid and the compressible mixture of this liquid with gas, in this case air.

The second paradox is that within the same pipeline, the liquid entering the pipeline changes its physical properties from an incompressible working medium to a compressible working medium.

The third paradox is that at the point where the flow changes its physical properties, the liquid and gaseous component flows

are coaxial, with the liquid component flow surrounding the gas component flow.

The fourth paradox is that in the zone that forms the boundary between the incompressible part of the flow and the compressible part of the flow, deep rarefaction or vacuum occurs under conditions where two coaxial flows each create an annular rarefaction zone, one created by the incompressible liquid flow and the second created by the compressible air flow. Both zones are coaxial, and the flow thickness in these zones does not exceed 100 micrometers for the liquid and 25 micrometers for the gas. The linear velocity in each of the flows in the rarefaction zone exceeds 100 meters per second, without the use of any additional energy sources.

The fifth paradox is that the mixture flow accumulates the kinetic energy of the flows of all components, and the kinetic energy of the mixture exiting the device exceeds the kinetic energy of the liquid component entering the device.

The sixth paradox is that under conditions of deep rarefaction and high linear flow velocity, in the boundary zone separating the incompressible liquid region and the compressible mixture region, a large number of composite fuel capsules are formed — more than 27 million spherical capsules with a diameter not exceeding 50 micrometers per liter of mixture or fuel composite.

The seventh paradox is that, if necessary, an additional liquid component of the fuel composite, for example water, may be drawn into the boundary zone between the compressible and incompressible parts of the flow. In this case, no additional energy is required to draw water into the liquid fuel flow and mix with it — only the energy of the liquid fuel flow itself is used.

The application of dynamic mixing technology for fuel mixture components in vehicle engines corresponds to an original algorithmic model. The technology of preliminary mixing and activation of fuel mixture components includes two main basic variants.

The first variant involves preliminary mixing of gasoline or diesel fuel with the amount of air necessary for optimal combustion conditions. After mixing, the mixture must be injected into the engine cylinders at the optimal time in order to avoid engine power losses associated with overcoming dead points of the engine motion conversion mechanism.

Currently, overcoming these losses in an engine consumes at least 62% and up to 70% of the fuel. The first variant of modernization of the internal combustion engine fuel system makes it possible to obtain equivalent engine torque while consuming at least 55% less fuel compared to currently produced standard engines.

In terms of distance traveled by a vehicle, if an engine currently consumes 1 gallon of fuel per 20 miles, then when using preliminary dynamic fuel component mixing technology, the engine should consume 1 gallon of fuel per at least 40 miles.

Tests of preliminary dynamic mixing technology in diesel fuel boilers have demonstrated high efficiency in reducing the concentration of toxic substances in exhaust gases. The reduction should exceed 40% compared to conventional engines.

Algorithm for Technology Verification

To test the effectiveness of the proposed technology, it is necessary to equip an internal combustion engine with a device for preliminary mixing of fuel mixture components, which must be designed and manufactured according to the specific parameters of the particular engine.

The size of the device must be equivalent to the fuel consumption rate required for engine operation under normal operating conditions.

To connect the device, it is necessary to design and manufacture injectors that must take into account the specific features of the engine and the capabilities of the device for preliminary dynamic mixing of fuel components.

For testing, a compressor must be prepared that is capable of providing the required amount of air at the required pressure, as well as all necessary instruments for measuring flow rate and pressure in all four compressed air supply lines to the device, which must also be designed and manufactured.

Pipelines must be installed from the device to each engine cylinder, and these pipelines must be equipped with pressure and flow measurement instruments, as well as safety valves; this system must be designed and manufactured.

An electronic sequential injection control system for each cylinder must be developed and manufactured, allowing fuel injection and ignition to occur at the moment when the engine motion conversion mechanism is not in one of the dead center positions. An algorithm and the necessary software must be developed for this system.

Figure 2. *Product size range: device for online optimization of fuel mixtures*

The engine fuel system must be modified, manufactured, and installed in order to provide the ability to control fuel flow rate and pressure before the device for preliminary dynamic mixing of fuel components. A fuel pump with adjustable pressure and flow rate and the necessary control equipment must be installed.

Control Parameters

During testing, the following main parameters must be monitored:

- engine torque;
- engine operating time at a specified torque;
- fuel consumption over a controlled engine operating time at a specified torque;
- concentration of toxic substances in exhaust gases (in accordance with environmental standards);
- auxiliary control parameters are not significant when comparing test results of the engine equipped with the device and the standard engine configuration.

Second Variant of the Technology

The second variant differs from the first in that water is added to the mixture in a proportion of 15% water to 85% organic fuel. In this case, fuel savings increase by 15%, and the distance per gallon increases to 46 miles.

Preparation for testing must additionally include the design and manufacture of a water supply system, which must include components for water purification, storage, water supply to the device, and instruments for monitoring water pressure, flow rate, and electrical conductivity.

The control parameters fully correspond to the control parameters in the first variant.

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NON-CONTACT ELECTROMAGNETIC RESONANCE QUALITY CONTROL OF LIQUIDS. (Non-Contact Electromagnetic Resonance Quality Control of Liquids, Including Water and Liquid Food Products within Smart Home Infrastructure Systems)

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Abstract

This paper presents a non-contact electromagnetic resonance system for quality control of liquid products, including liquid food products. The increasing importance of liquid quality monitoring is driven by global environmental changes, the widespread use of genetically modified products, and the growing application of chemical fertilizers, all of which introduce new risk factors affecting product safety and composition. Traditional quality control methods are often insufficient for modern multicomponent and composite liquid products. To address these challenges, a sensor system based on magnetic resonance principles has been developed, enabling advanced, reliable, and technologically relevant liquid quality assessment.

Keywords: *Water and liquid product quality control; Electromagnetic resonance quality monitoring; Magnetic resonance-based sensors; Technical requirements for the technological measurement principle; Electromagnetic resonance spectroscopy; Genetically modified liquid products; Composite liquid products; Deep global processes; Liquid food products; Increase in the use of chemical fertilizers; Alternating electromagnetic field; Vortex electromagnetic field; Generation of an alternating electromagnetic field in the spatial domain containing the test sample; Product refinement to the stage of mass production*

Technical Requirements for the Measurement Principle

- The implementation of the technological measurement principle shall ensure:
- Low specific cost per measurement;
- High measurement reliability;
- Simplicity of operation, enabling use by minimally trained personnel or for domestic drinking water quality assessment;
- Compact equipment dimensions;
- Integration capability into existing technological schemes and equipment complexes;

- High throughput performance;
- Continuous 24-hour operation capability;
- High efficiency and high repeatability of results;
- Capability for simple and reliable automation;
- Compatibility with disposable technologies and materials;
- Remote monitoring and remote access to monitoring results;
- Comparative assessment of process and water quality based on a limited number of technological indicators.

Product Description

The product based on the application is:

Water Quality RST-SENSOR

The product consists of a pipeline section with a resonance sensor mounted on its external surface and threaded fittings at both ends for connection to existing pipelines.

A sensor cable is designed for connection to a control and analytical unit or to an integrated pipeline management and control system.

Size Range

- Pipeline diameters from **1/8 inch to 4 inches** – equipped with annular sensors;
- Diameters above **4 inches** – equipped with sector-type sensors;
- Manufactured from various structural materials.

Key Technical Requirements

Measurement Accuracy

The device shall detect variations in chemical composition equivalent to concentrations of **0.000001 mg/L**.

4.2 Simplicity of Design

Only standard or mass-produced components and materials shall be used.

The product shall consist entirely of standard pipeline fittings, ensuring:

- High reliability;
- Maintainability;
- Low manufacturing cost;
- Production without specialized technological equipment.

Reliability and Durability

- Mean time to first failure ≥ 10,000 hours;
- Operational lifetime ≥ 10 years.

Complete Non-Contact Measurement

No direct contact with the measured liquid.

Sensitivity shall not decrease with a dielectric barrier up to 2.5 mm between the sensing element and the liquid.

Integration Capability

Compatible with:

- Industrial process lines,
- Boilers and steam systems,
- Municipal water networks,
- Agricultural irrigation systems,
- Industrial water supply systems.

Low Energy Consumption

Total power consumption shall not exceed **50 W**.

Aggressive and Toxic Liquids

Materials shall permit monitoring of aggressive and toxic liquids.

Ultra-Pure Liquids

Materials shall not contaminate or degrade when exposed to ultra-pure liquids.

Automation Compatibility

Sensor signals shall be compatible with commercially available industrial and agricultural control processors.

Autonomous Operation

The device shall operate independently without integration into centralized control systems.

The device may also function as a **level sensor**, without structural modification from the water quality control configuration.

The fundamental structural and technological principles of the product architecture have been developed.

A baseline universal prototype has been manufactured.

A cycle of preliminary testing has been conducted.

The universal prototype has been refined based on the results of preliminary testing.

Materials for a patent application have been prepared.

A patent and licensing protection strategy for the technology has been developed.

Activities Required for Transition to Mass Production and Market Deployment

To advance the product to mass production and the active marketing phase, the following activities shall be completed:

- Development of initial product technical requirements incorporating feedback from potential customers;
- Preparation of a formal project technical specification;
- Development of a technical proposal, including design, fabrication, and testing of product models;
- Development of the technical design phase, including engineering, prototype manufacturing, and testing;
- Preparation of detailed working design documentation, including fabrication and testing of pilot units;
- Conformity assessment and certification of products in accordance with applicable standards;
- Certification at an accredited standards institute;
- Production of an initial pilot batch;
- Pilot industrial operation of the initial production batch;
- Development of a comprehensive marketing strategy;
- Preparation of a production and commercialization program for market adaptation;
- Development of a warranty and service support system;
- Identification of a strategic partner;
- Launch of the first phase of active marketing.

Target Industries

Resonance-based devices for non-contact quality monitoring of water and other liquids shall be fully suitable for effective operation in the following industries:

- Pharmaceutical industry;
- Microbiological industry;
- Semiconductor manufacturing;
- Microelectronics;
- Power generation, including nuclear power plants;
- Industrial HVAC systems;
- Water treatment and purification across industrial, residential, and public infrastructure;
- Fine chemical production;
- Cosmetic manufacturing;
- Production of alcoholic and non-alcoholic beverages;
- Food processing industry;
- Greenhouse agriculture;
- Agricultural irrigation systems;
- Electroplating and electrochemical production;
- Oil extraction and production.

Mass-Market Products Resulting from Project Completion

The project is expected to result in the following commercially scalable products:

- Household drinking water purity indicator;
- Industrial water purity indicator;
- Pipeline-sensor for non-contact conductivity monitoring of liquids, based on industrial PVC pipeline components;
- Operating diameters: 1/16; 1/8; 1/4; 3/8; 1/2; 3/4; 1; 1–1/4 inches and increasing in 1/4-inch increments up to 4 inches;
- Designed for integration into automated industrial control systems;
- Pipeline-sensor for non-contact liquid conductivity monitoring, based on polypropylene industrial pipeline components;
- Operating diameters as specified above;
- Designed for integration into automated control systems;
- Autonomous pipeline-sensor for liquid conductivity monitoring, based on PVC industrial components;
- Operating diameters as specified above;
- Autonomous pipeline-sensor for liquid conductivity monitoring, based on polypropylene industrial components;
- Operating diameters as specified above;
- Pipeline-sensor systems as described above, manufactured using polycarbonate industrial pipeline components;
- Pipeline-sensor systems manufactured using Teflon, composite polymer materials, thermosetting plastics, polymer composites with fillers, and high-temperature-resistant materials;

- Sensor systems integrated into automated control complexes for non-contact liquid quality monitoring in pipelines exceeding 4 inches in diameter, manufactured from PVC, polypropylene, thermally resistant polymers, or thermosetting plastics;
- Sensor systems for monitoring liquids supplied to agricultural irrigation systems;
- Sensor systems for monitoring liquids in irrigated agriculture complexes;
- Sensor systems for monitoring liquids in greenhouse agricultural complexes;
- Non-contact level sensor systems with horizontal installation configuration;

1. Non-contact level sensor systems with vertical installation configuration;

- Integrated systems combining level sensing and liquid quality monitoring functions.

Non-Contact Electromagnetic Resonance Quality Control of Liquid Products

Non-contact electromagnetic resonance quality control of liquid products, including liquid food products, represents one of the advanced smart technologies attracting significant interest from entrepreneurs and technical specialists.

The quality of liquid products – particularly liquid food products – has become critically important due to ongoing global processes, including climate change, the widespread use of genetically modified products, and additional risk factors such as the continuous increase in the application of chemical fertilizers.

As technologists emphasize, traditional quality control methods are no longer sufficient for monitoring modern composite and multicomponent food products.

To enable liquid quality control at a level consistent with contemporary technological requirements, a sensor system operating on magnetic resonance principles has been developed.

Physical Principle of the Method

The method is based on the generation of an alternating electromagnetic field in the spatial domain where the test sample is located. This field serves as an intermediary coupling medium between the resonance circuit and the sample under examination.

The resonance circuit simultaneously acts:

- as an emitter of the electromagnetic field, and
- as a receiver (sensitive element) detecting distortions introduced into the field by the test sample.

Even in the absence of a sample, the alternating electromagnetic field generated by the solenoid represents the superposition of two electromagnetic fields varying in opposite phase:

1. A field generated by the variation of magnetic induction in the solenoid of the sensing element, resulting in a vortex electric field (Maxwell–Faraday equation).
2. A field generated by variation of the electric field caused by the potential difference between:
   - the most distant turns of the solenoid (if the sample is placed inside the solenoid), or
   - the turn closest to the measured element and the element itself (if positioned opposite the end of the solenoid),
3. resulting in a vortex magnetic field (Ampère's circuital law with Maxwell's correction).

Interaction with the Test Sample

Under the influence of the external alternating electromagnetic field, the following phenomena may be simultaneously induced in the test sample, depending on its physical nature:

- Linear conduction currents;
- Eddy conduction currents;
- Linear displacement currents (caused by dielectric polarization);
- Eddy displacement currents;
- Linear ionic currents;
- Eddy ionic currents (ordered ion motion).

According to the principle of field superposition, these induced electrical phenomena distort the external alternating electromagnetic field.

These distortions are detected by the solenoid of the resonance sensor.

Equivalent Electrical Model

The resonance circuit of the sensing element responds to these distortions as if additional electrical components were introduced into the circuit:

- Additional capacitance,
- Additional inductance,
- Additional resistance.

The combination of these additional capacitive, inductive, and resistive components forms an additional impedance introduced into the system by the test sample.

This additional impedance is the parameter measured by the resonance sensor.

Changes in the resonance circuit parameters result in modifications of its amplitude–frequency characteristics, specifically:

- Shift in resonance frequency,
- Change in resonance amplitude.

By analyzing the magnitude and nature of these changes, the impedance characteristics of the sample can be determined.

Device Design

The magnetic resonance device for water and aqueous solution quality control consists of:

- A pipeline section;
- A ring-shaped sensor mounted externally on the pipe surface;
- A power supply unit;
- A control, amplification, and signal identification system.

The system may optionally include a wireless transmission module for sending the processed signal to:

- An operator console,
- A computer display,
- A mobile device.

Calibration and Operation

The system is calibrated using a reference sample of water or another liquid, taking into account local operating conditions.

The sensor detects any deviation in the state of the monitored liquid.

The signal is identified and transmitted to the operator console, computer monitor, or mobile device.

The measurement frequency can be configured within the range:

- From one test every 0.1 seconds;
- To one test per minute.

Key Sensor Parameters

The primary performance parameters of the resonance sensor for water quality control include **accuracy and sensitivity**.

The principal parameter is **sensitivity**, defined as the ability to detect, distinguish, and identify variations equivalent to **0.000001 grams per liter (1 µg/L)**.

Limitations of Conventional Technologies

In conventional liquid quality control systems:

- Highly qualified personnel are required, with labor costs exceeding USD35 per hour;
- Typically, no more than one test per day can be performed;
- Between tests, the condition of the liquid remains unmonitored;
- This gap may result in delayed detection of contamination or system failure;
- The time between fault detection and corrective action is prolonged due to lack of continuous monitoring;
- Information transmission is not real-time, thereby increasing the risk of emergency situations.

Proposed Remote Monitoring Method

The proposed method for remote monitoring of material object parameters includes:

- Formation of a three-dimensional spatial system in which the sensing element surrounds the monitored element;
- Alignment of symmetry centers of the cross-sections of both sensing and monitored elements;
- Stabilization of a uniform gap between the external surface of the monitored element and the sensing element;
- Generation of an energy-saturated spatial region in the form of an alternating electromagnetic field with controlled and adjustable intensity;
- Exposure of the monitored element to the alternating electromagnetic field and induction of:

– Linear and eddy conduction currents;

– Linear and eddy displacement currents,

– Linear and eddy ionic currents;
- Identification and comparative analysis of distortions introduced into the electromagnetic field;
- Perception of these distortions by the resonance circuit as equivalent additional electrical components (capacitance, inductance, resistance);
- Measurement of resonance circuit parameter changes (frequency shift and amplitude variation);
- Evaluation of the resulting impedance of the monitored object, reflecting its state parameters.

Method for Liquids, Mixtures, and Aerosols

For liquids, liquid mixtures, liquid-gas mixtures, or aerosols, the method further includes:

- Enclosing the monitored element within a geometrically stabilizing shell;
- Ensuring concentric alignment between sensing and monitored elements;
- Maintaining a stable uniform dielectric gap;
- Generating a controlled alternating electromagnetic field characterized by frequency and field intensity;
- Sequential variation of field parameters proportional to the number of components in the material object;
- Sequential measurement of impedance variations corresponding to individual components.

The "energy-saturated space" in this context refers to an alternating electromagnetic field defined by frequency and field strength.

Controlled modulation of this field ensures measurement flexibility and high precision across various material types.

Importantly, the method does not differentiate between:

- Solid or liquid materials,
- Liquid or solid mixtures,
- Liquid-gas systems.

Calibration is therefore limited to a minimal number of technological parameters.

Application to Liquid Food Products

From a practical standpoint, non-contact monitoring of liquid food products suggests that sensor sensitivity and measurement accuracy are strongly influenced by the number of components within the liquid mixture.

Transitioning, even partially, to **multicomponent packaging** would significantly reduce the number of components monitored simultaneously, thereby:

- Increasing measurement accuracy;
- Improving reliability;
- Enabling practical implementation of non-contact measurement technology.

Multicomponent Packaging Concept

Advanced designs of dual-component plastic packaging have been developed, along with non-contact measurement methodology compatible with smart home infrastructure modules.

The bottle design consists of two coaxial cylindrical chambers of identical outer diameter.

When placed inside a vertical or horizontal solenoid sensor:

- Independent integral amplitude values can be measured for each chamber;
- Laboratory reference amplitude values are determined for each liquid;
- At points of sale or storage, measured amplitude values are compared with reference values.

Deviation indicates:

- Contamination,
- Structural degradation,
- Fermentation processes,
- Biological decomposition.

Operational Advantages

Because the monitoring process does not require specialized training:

- Any operator can perform quality checks;
- Continuous monitoring becomes feasible;
- Product safety increases;
- Consumer quality of life improves without substantial capital investment.
- **Experimental Validation**

To demonstrate feasibility, experimental laboratory equipment was developed.

Ionized water was used as the monitored medium.

To ensure samples differed only in pH level:

- Preparation was performed in a flow-through electrochemical reactor;

- Municipal water (mineralization approximately 40 mg/L, San Francisco) was ionized;
- The flow was divided into two parallel streams:
  – One acidic,
  – One alkaline.

This configuration allowed controlled testing of sensor sensitivity to compositional changes.

In order to additionally track the influence of water layer thickness on the result, the sensor was immersed in communicating cylindrical vessels whose diameters differed by a factor of two.

As demonstrated by the tests and measurements, the amplitude in the measured samples of the same water, with a pH level of 3 units and an alkalinity level of 11 units (with equal initial mineralization of 40 milligrams), differed by 1000 millivolts.

This simple experiment proves the possibility of monitoring even the smallest changes in the condition of liquids in each of the chambers of a two-component package.

The obtained sensor sensitivity makes it possible to detect, during monitoring, changes not only in each component separately, but also to track the slightest variations in the components through their sequential comparison with each other.

Such a comparison method makes it possible to predict potential variations in the qualitative composition of the mixture obtained after mixing both components.

Thus, it becomes entirely realistic to conclude that, in order to increase the level and accuracy of detection and identification of even the smallest changes in the quality of water and liquid food products, it is advisable to use multicomponent packaging for storage, transportation, and effective mixing prior to consumption.

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MAIN DIRECTIONS OF IMPLEMENTING THE "1C: ENTERPRISE" SYSTEM BASED ON CLOUD TECHNOLOGIES IN BANKING REGISTRY SERVICES

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Abstract

This article examines contemporary approaches to the implementation of cloud technologies in the "1C: Enterprise" system for organizing registry services in banking and enterprise environments. The architectural features of cloud-based solutions are analyzed, including Software as a Service (SaaS), web client, and thin client models. The study identifies the principal directions of cloud technology deployment: within an enterprise, within a holding structure, for client-facing services, and in the web services model. Practical aspects of implementation are demonstrated through examples of XML-based data exchange and web service integration. The results confirm that the adoption of cloud technologies significantly enhances management efficiency, reduces operational and infrastructure costs, and ensures scalability and flexibility of information systems.

Keywords: *cloud technologies, 1C: Enterprise, SaaS, web client, thin client, ERP, information systems*

Introduction

Increasing enterprise profitability, improving personnel efficiency, and establishing an optimal management structure are among the primary objectives of modern management systems. In conditions characterized by uncertainty, volatility, and risk, decision-makers are required to process large volumes of heterogeneous data while maintaining control over multiple financial and operational units.

To address these challenges, corporate information systems (CIS) are widely employed. One of the most prominent solutions is the "1C: Enterprise" system, which provides comprehensive automation of accounting processes, enterprise resource planning (ERP), and analytical support for managerial decision-making (Mell, P., Grance, T., 2011; Laudon, K., Laudon, J., 2020).

The "1C: Enterprise" system extends beyond traditional accounting automation by enabling the management of material flows, human resources, procurement, production processes, and product distribution. Additionally, it supports the generation of regulatory reports required by supervisory authorities (Laudon, K., Laudon, J., 2020).

The current stage of information technology development is characterized by the rapid expansion of cloud computing technologies, which provide remote access to computing resources, storage systems, and software applications via the Internet. These technologies play a critical role in the digital transformation of enterprises and public sector organizations (Silberschatz, A. 2018; Erl, T., 2013).

Essence of cloud technologies

Cloud computing represents a model for delivering computing resources as services over a network, typically the Internet or a private local network. In this paradigm, users access applications, data, and computational resources remotely through standardized interfaces without the need for local installation or maintenance (Silberschatz, A. 2018; Pressman, R. 2014).

According to the definition provided by the National Institute of Standards and Technology (NIST), cloud computing is characterized by the following essential features (Mell, P., Grance, T., 2011):

- on-demand self-service;
- broad network access;
- resource pooling;
- rapid elasticity and scalability;
- measured service (pay-as-you-go model).

Within this framework, the user device functions primarily as a terminal interface, while core processing and data storage operations are performed on remote servers or distributed data centers (Tanenbaum, A. 2007; Pressman, R., 2014).

Use of cloud technologies in the "1C: Enterprise" system

The integration of cloud technologies into the "1C: Enterprise" system ensures platform independence, allowing users to access the system regardless of operating system or device type. The computational workload is fully handled by the server infrastructure, while users interact with the system through web browsers or client applications (Erl, T. 2013; Armbrust, M. et al. 2010).

The system supports several advanced features, including:

- database access via HTTP/HTTPS protocols;
- data exchange using FTP and web services;
- web client operation without local installation;
- support for a large number of concurrent users;
- multitenancy (shared infrastructure for multiple users);
- SaaS-based deployment models (Armbrust, M. et al. 2010; Stair, R., Reynolds, G. 2018).

Cloud technologies within an enterprise

The internal cloud model allows employees to access enterprise systems from any location using standard web browsers. Authentication is performed via server address, login credentials, and secure access protocols.

In addition to internal personnel, access can be granted to external stakeholders such as suppliers and contractors, significantly expanding system functionality and collaboration capabilities (Erl, T. 2013).

The thin client model is also widely used, where users run a lightweight application that connects to a centralized server infrastructure.

Practical example: XML and Web services integration

```
XMLHTTP.Open("POST", Address, False);
XMLHTTP.Send(XMLText);
ResponseString = XMLHTTP.ResponseText;
```

This mechanism enables automated data exchange between distributed systems, allowing real-time retrieval and processing of information.

Advantages:

- ability to use low-performance hardware;
- enhanced mobility of employees;

- simplified integration of external users and partners (Armbrust, M. et al. 2010).

Case study: Azərsu (Azersu)

In the Azərsu enterprise, cloud technologies are actively used to automate water consumption accounting and operational processes in accordance with digital transformation strategies (Mell, P., Grance, T. 2011; Laudon, K., Laudon, J. 2020).

Scenario:

- employees collect meter readings via mobile devices;
- data is transmitted through a web client to the "1C" system;
- centralized processing is performed on cloud servers.

Results:

- •reduction of data entry errors (Pressman, R., 2014);
- •increased operational efficiency (Laudon, K., Laudon, J. 2020);
- •elimination of paper-based workflows.

Cloud technologies within a holding structure

In holding organizations, cloud technologies enable centralized data management and significant cost reduction. Instead of maintaining separate databases for each division, a unified information system is implemented and accessed via cloud infrastructure (Stair, R., Reynolds, G., 2018).

Advantages:

- reduced maintenance and support costs;
- centralized system updates;
- unified information space across all divisions.

For geographically distributed enterprises such as Azərsu, centralized cloud databases ensure consistency and transparency of data across regions.

Cloud technologies for clients

Cloud-based systems provide clients with direct access to enterprise services via the Internet, eliminating the need for software installation.

Advantages:

- ease of access;
- global availability;
- improved customer engagement and interaction (Turban, E., 2015).

Example: Customer self-service portal

SaaS-based client platforms enable users to:

- check account balances;
- perform online payments;
- submit meter readings.

Such systems are typically built on modern web technologies and RESTful APIs (Fielding, R., 2000).

Results:

- increased customer satisfaction (Turban, E., 2015);
- reduced workload on operational departments (Pressman, R., 2014).

Operation in Web services model (SaaS)

The SaaS model allows users to access software as a service without owning the infrastructure. All technical operations are managed by the service provider.

Provider Responsibilities:

- ensuring system availability and uptime;
- software updates and maintenance;
- data security and protection; backup and recovery mechanisms.

Advantages:

- elimination of infrastructure costs;
- high accessibility;
- continuous use of up-to-date software versions (Pressman, R., 2014; Fielding, R. 2000).

SaaS and integration with banks

Integration through web services is a fundamental component of modern IT ecosystems (Fielding, R. 2000; Papazoglou, M., 2012).

Example: Payment automation

In Azərsu, payment data is automatically transmitted from banking systems to the "1C" system via APIs, consistent with Service-Oriented Architecture (SOA) principles (Papazoglou, M., 2012).

Results:

- reduction of manual processing operations (Pressman, R., 2014);

- increased accuracy of financial data (Stair, R., Reynolds, G., 2018).

Emergency management

Cloud-based systems enable efficient monitoring and management of emergency situations, aligning with the concept of smart infrastructure (Batty, M. 2018).

Example: Water Supply Incidents

- incident registration in the system;
- task assignment to mobile response teams;
- real-time status updates.

Results:

- reduced response time (Batty, M. 2018).;
- improved resource allocation efficiency.

Analytics and forecasting

Cloud platforms support advanced data analytics and predictive modeling, consistent with Big Data and predictive analytics paradigms (Provost, F., Fawcett, T., 2013).

Example: Water consumption analysis

The "1C" system enables:

- forecasting consumption patterns;
- detecting anomalies;
- analyzing customer debts.

Results:

- optimization of resource usage (Provost, F., Fawcett, T., 2013).
- reduction of losses and inefficiencies (Batty, M. 2018).

Discussion

The conducted analysis demonstrates that the cloud-based implementation of the "1C: Enterprise" system has multidimensional value. At the technological level, it improves accessibility, scalability, update management, and integration capacity. At the organizational level, it supports centralized control, distributed interaction, and user mobility. At the economic level, it reduces infrastructure expenditure and maintenance costs (Erl, T., 2013; Armbrust, M. et al. 2010; Stair, R., Reynolds, G. 2018).

At the same time, the effectiveness of cloud implementation depends on the selected deployment model and the operational profile of the organization. The internal cloud model is most suitable for improving employee mobility and internal coordination. The holding cloud model is especially effective for geographically distributed structures. The customer cloud model is most relevant for digital service delivery, whereas the SaaS model offers the greatest reduction in technical overhead.

From an academic standpoint, the findings confirm that cloud transformation should not be viewed solely as infrastructure outsourcing. Rather, it represents a structural reconfiguration of enterprise information architecture, data flows, and user interaction logic. This interpretation is particularly important for registry services connected with banking operations, where accuracy, integration reliability, and process continuity are crucial.

Conclusion

The implementation of cloud technologies in the "1C: Enterprise" system represents a strategic direction in the evolution of corporate information systems. Cloud-based solutions improve management efficiency, reduce infrastructure and operational costs, and provide scalability and flexibility.

The study has shown that the main implementation directions may be grouped into four interrelated models: internal enterprise cloud, holding cloud, client-oriented cloud access, and SaaS-based operation. Each of these models contributes to the digital transformation of enterprise processes in different ways, while together they form a comprehensive architecture for scalable and service-oriented information management.

The primary models – internal cloud, holding cloud, client-oriented systems, and SaaS – offer comprehensive capabilities suitable for organizations of different sizes and structures.

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NEUROADAPTIVE PILOT CABIN INTERFACES: NEW HORIZONS IN AVIATION ERGONOMICS

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[1] Independent research

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Abstract

The evolution of cockpit design has historically followed a trajectory from purely mechanical instrumentation toward integrated digital environments and increasingly automated flight management systems. Yet, the cognitive and physiological limitations of pilots remain decisive in shaping aviation safety and efficiency. Neuroadaptive interfaces represent a novel paradigm that integrates real-time monitoring of neural, ocular, and psychophysiological signals into adaptive cockpit systems capable of dynamically adjusting displays, workload distribution, and control modalities. This article explores the emerging horizon of aviation ergonomics where human–machine interaction is redefined through neuroadaptive technologies. By synthesizing findings from cognitive neuroscience, human factors engineering, and applied aviation research, the paper highlights both the promises and challenges of embedding neuroadaptive systems into future cockpits. The discussion underscores technical architectures, adaptive display logic, experimental validation, and ethical implications, while emphasizing the role of these systems in augmenting situational awareness, mitigating fatigue, and preventing human error.

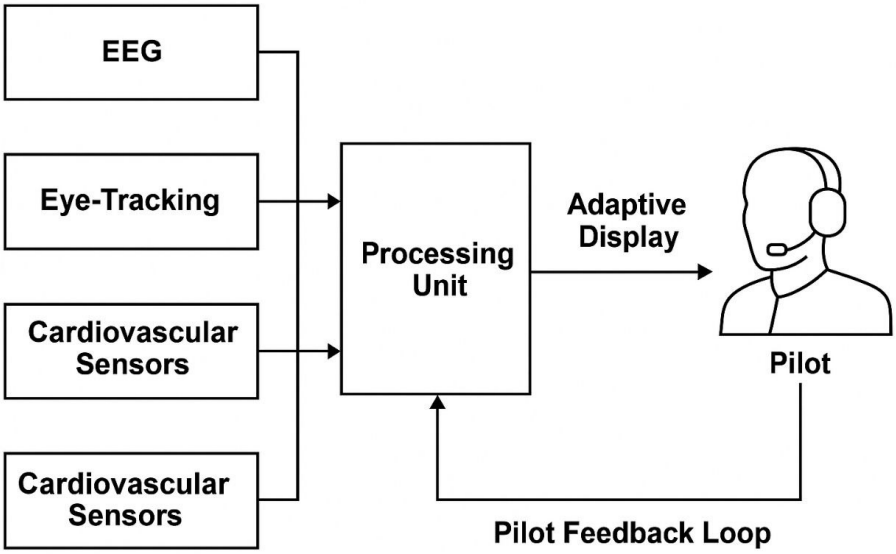
Keywords: *neuroadaptive interface; cockpit design; aviation ergonomics; brain–computer interface; adaptive display; cognitive workload; pilot–automation interaction*

The modern flight deck is an ecosystem where human cognition is in continuous negotiation with a dense web of information flows. Over decades, cockpit design has been optimized to improve readability, reduce redundancy, and integrate automation, yet incidents continue to reveal that human error is the dominant factor in aviation accidents. While automation has reduced pilot workload in certain domains, it has simultaneously introduced new vulnerabilities, such as automation complacency and loss of manual flying skills (Gateau, T., Durantin, G., Lancelot, F., Scannella, S., & Dehais, F., 2015).

At the core of neuroadaptive design lies the continuous measurement of signals that reflect the pilot's mental state. Electroencephalography (EEG) provides real-time data on attentional focus, workload, and fatigue. Eye-tracking allows detection of scan patterns, fixation durations, and micro-saccades that correlate with situational awareness. Heart rate variability and galvanic skin response contribute additional dimensions

of psychophysiological monitoring. By fusing these multimodal signals, adaptive systems can infer states of overload, underload, stress, or disengagement. Instead of presenting information in a static format, the cockpit could dynamically restructure displays, highlight critical parameters, or even modulate levels of automation support.

Figure 1. *Conceptual diagram of a neuroadaptive cockpit*



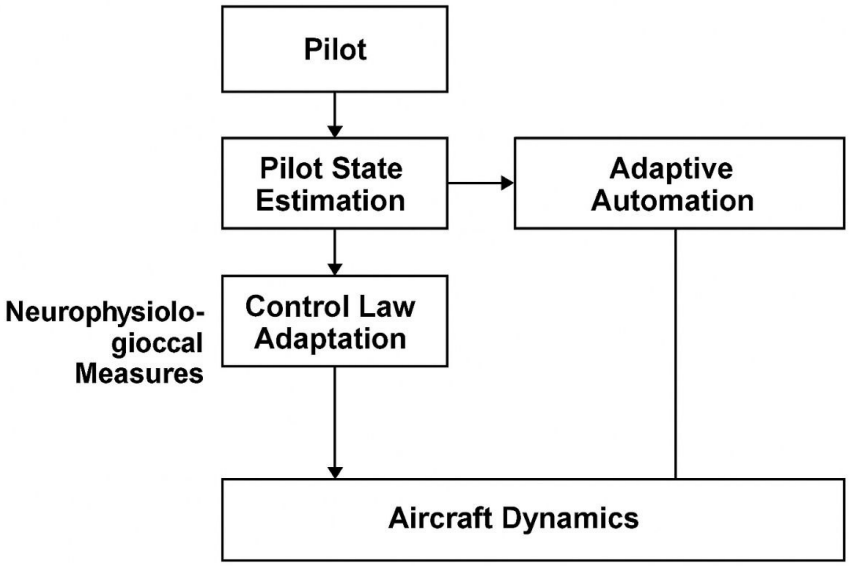
This conceptual framework moves beyond earlier generations of adaptive automation, which relied primarily on task performance metrics. Traditional adaptive systems could alter autopilot engagement based on flight phase or operator input, but they lacked direct access to the pilot's cognitive condition. Neuroadaptive systems provide this missing link by sensing workload directly.

For example, if EEG analysis indicates an elevated theta–beta ratio associated with fatigue, the interface could increase the salience of auditory alerts or delegate routine monitoring tasks to automation (Parasuraman, R., & Wickens, C. D., 2008). Conversely, if eye-tracking reveals diminished scanning of engine parameters during high workload phases, the display could reconfigure to foreground critical indicators.

The ergonomic implications of this transition are profound. Human–machine interaction in aviation has historically oscillated between two poles: the pilot as master of the machine and the pilot as supervisor of automation. Neuroadaptive interfaces propose a third model: the cockpit as an intelligent partner attuned to the pilot's mental state. In this partnership, responsibility is neither entirely human nor entirely automated but dynamically shared (Van de Merwe, K., van Dijk, H., Zon, R., 2012). This can mitigate two recurrent sources of risk – information overload and loss of engagement. By reducing unnecessary visual clutter when workload is high, and by reintroducing meaningful manual engagement when workload is low, neuroadaptive systems can keep the operator within an optimal performance envelope.

Technically, the implementation of such systems requires robust signal processing pipelines. EEG signals in a cockpit environment are susceptible to noise due to motion, muscle artifacts, and electromagnetic interference. Advances in dry electrode technology and adaptive filtering algorithms are critical enablers (Borghini, G., Aricò, P., Di Flumeri, G., Colosimo, A., Bonelli, S., Golfetti, A., & Babiloni, F., 2015). Similarly, eye-tracking must operate reliably under variable lighting, head movements, and the use of oxygen masks or visors. Sensor fusion algorithms integrate these diverse signals to produce stable estimates of cognitive workload. Machine learning models trained on large datasets of pilot performance play a central role in calibrating the interface to individual users, accounting for inter-individual variability in physiological baselines.

Figure 2. *Adaptive display logic illustrating transitions between high workload, optimal workload, and low workload states, and corresponding cockpit adaptations*



Vision-based technologies, and eye-tracking in particular, present a uniquely advantageous option. Eye trackers can be integrated directly into cockpit panels, they provide non-intrusive and real-time measures of gaze behavior, and over the past decade they have become reliable, affordable, and widely available (Borghini, G., Aricò, P., Di Flumeri, G., Colosimo, A., Bonelli, S., Golfetti, A., & Babiloni, F., 2015). The scientific rationale is grounded in the nature of human vision itself. Because the highest acuity is limited to the foveal region, the eyes constantly move across the visual field. Fixations, where gaze remains relatively stable and information is acquired, alternate with saccades, the rapid jumps that shift attention. The sequence of these oculomotor events provides a window into the allocation of attention, perceptual encoding, and decision-making strategies. Eye-movement research in aviation dates back to the pioneering simulator studies of Fitts in the 1950s, who observed that experienced pilots demonstrated shorter fixations and more efficient instrument sampling patterns than novices. At that time, the technology required complex apparatus and laborious manual analysis. Today, with lightweight cameras and automated processing, the method can be applied seamlessly in simulators and even in operational aircraft.

The integration of gaze analysis into aviation is commonly conceptualized in four successive stages, each representing a deeper embedding of the technology into training, investigation, and operational adaptation. The first stage is the use of gaze data in training and performance analysis. The second involves the systematic recording of pilots' gaze on board as part of the flight data infrastructure. The third envisages real-time adaptation of the flight deck displays and alerts according to ongoing gaze allocation. The fourth and most ambitious stage extends to gaze-based aircraft adaptation, where the automation itself can intervene or modify configuration on the basis of pilot attentional states.

In the first stage, gaze recording serves as an objective measure of skill, a tool for example-based learning, and a basis for debriefing (Baldwin, C. L., & Penaranda, B. N., 2012). Across domains as diverse as radiology, chess, and surgery, experts have been shown to rely on shorter fixations and more targeted scanning strategies. The same holds in aviation, where novice pilots typically waste time attending to irrelevant instruments, while experts concentrate on the few parameters that matter most in each flight phase. Empirical studies in helicopter navigation have quantified this expertise effect: each additional thousand hours of flight experience was associated with reduced dwell times and more efficient transitions between map and external view (Jetzek, T., Bender, M., & Helmert, J. R., 2021). In experimental settings, pilots who

successfully diagnosed malfunctions directed their gaze toward the cues most relevant to the fault, whereas unsuccessful pilots over-attended to less diagnostic indicators. This phenomenon has been described as an "information reduction strategy," where experts learn to filter irrelevant data. By capturing fixation durations, dwell distributions, and scan path transitions, trainers can derive quantitative indices of expertise that complement traditional evaluations.

The second stage of integration concerns the systematic recording of gaze on board as part of flight data collection (Fairclough, S. H., & Lotte, F., 2020). Modern aircraft already carry flight data recorders and cockpit voice recorders, yet these devices cannot capture what information the crew actually perceived. Gaze recording would extend the "black box" into a truly human-centered data recorder. Analysis of such records could determine whether a pilot saw a warning but misinterpreted it, or whether it was never perceived in the first place. Furthermore, gaze records allow reconstruction of crew coordination, since pilots routinely observe each other's actions, such as hand movements on levers or buttons. Pointing and mutual monitoring are key components of shared situation awareness, and gaze data provide a trace of these interactions. The benefit extends beyond investigation: manufacturers could use aggregated gaze records to evaluate the usability of cockpit interfaces and redesign displays that consistently fail to attract attention when needed (Prinzel, L. J., Freeman, F. G., Scerbo, M. W., Mikulka, P. J., & Pope, A. T., 2003).

The third stage represents a shift from passive recording to active operational use, where gaze information adapts cockpit interfaces in real time (Lee, J. D., & See, K. A., 2004). Extensive laboratory research has demonstrated that eye movements can reveal degraded cognitive states: spatial disorientation, fatigue, attentional tunneling, or surprise when automation behaves unexpectedly. They can also signal intention. Pupil dilation and anticipatory fixations have been shown to predict forthcoming decisions in navigation tasks. In maritime simulations, gaze patterns foreshadowed maneuvering choices; in driving, they indicated lane change intentions; in nuclear operations, they disclosed thought processes about system states. Translating these findings to aviation, one can envision flight decks that monitor gaze allocation and intervene when critical information is neglected.

Operational incidents underscore the potential. In 2011, Air France flight AF471, a Boeing 777–200 on approach to Paris Charles de Gaulle, suffered from a monitoring breakdown (Baldwin, C. L., & Penaranda, B.N., 2012). When the automatic landing mode disengaged, the pilot flying mistakenly pressed the wrong switch, while the pilot monitoring focused almost exclusively on flap retraction. Neither attended to the attitude indicator or the aircraft's energy state until a relief pilot intervened verbally. Eye-tracking could have detected both the absence of fixation on pitch attitude and the excessive dwell on flap configuration. In such a scenario, the system might have temporarily concealed the flap display or highlighted the neglected indicators to redirect attention. Similarly, in 2012, a Skippers Aviation Dash 8–300 descended with an unsafe sink rate because both pilots concentrated on external visual references rather than vertical speed and altitude (Sumwalt, R., Cross, D., Lessard, D., 2015). A gaze-aware system could have detected the prolonged external fixation and gently re-engaged attention toward critical flight parameters.

Implementation of such adaptation requires formalizing rules for each flight phase: for every instrument, define a maximum permissible dwell time and a maximum time without fixation. If either threshold is violated, the system issues an adaptive cue – an auditory chime, a transient highlight, or a brief retraction of secondary information (Gateau, T., Durantin, G., Lancelot, F., Scannella, S., Dehais, F., 2015). The logic is straightforward: while looking does not guarantee seeing, not looking almost certainly precludes perception. In this way, eye tracking reduces the risk of "looked but failed to see" and almost eliminates "not looked, therefore failed." Challenges remain, including prioritizing alerts to avoid overload and ensuring that interventions are subtle enough not to distract, but the framework is conceptually clear.

The fourth stage, gaze-based aircraft adaptation, extends the principle from interface

cues to automation authority (Schmidt, E. A., Schrauf, M., Simon, M., Fritzsche, M., Buchner, A., & Kincses, W. E., 2009). The underlying problem is the limitation of human attentional resources. Modern automation already intervenes in emergencies; for example, fighter aircraft perform automatic pull-up maneuvers if pilots fail to react to terrain warnings. Gaze integration could allow earlier and more context-sensitive interventions.

If the system detects that neither pilot has monitored altitude or mode annunciations for a critical interval, and if the aircraft is trending toward controlled flight into terrain, it could automatically re-engage protective modes or adjust flight path. Case studies highlight the relevance. In 2010, Flybe flight BE1794 descended below cleared altitude after the crew became distracted by an avionics fault, failing to notice disengaged autopilot modes (Sumwalt, R., Cross, D., Lessard, D., 2015). Only the ground-proximity warning system prevented disaster. If gaze monitoring had revealed the neglect of altitude and mode annunciator, the automation might have restored the modes proactively. A similar situation occurred in 2008 with Flybe flight BEE247S, where the crew failed to monitor the flight director, descending below glide slope until corrected by air traffic control (Sumwalt, R., Cross, D., Lessard, D., 2015). Here too, absence of fixations could have triggered either an alert (stage III) or an automated correction (stage IV).

Stage IV, however, poses formidable certification barriers. Any system capable of overriding pilot input must meet catastrophic-level safety requirements: probabilities of false intervention must be less than one in a million or one in a billion, depending on aircraft class. Current video-based eye trackers cannot guarantee gaze capture in all conditions with that level of reliability. Moreover, false positives, where the system misinterprets gaze patterns as neglect, could have dangerous consequences. For these reasons, operational deployment of stage IV is unlikely within the next two decades. Nevertheless, conceptual studies demonstrate how gaze-based authority could become an additional safeguard when human monitoring lapses.

Taken together, the four stages trace a continuum from training enhancement through investigative support, operational adaptation, and ultimately integrated human-machine collaboration (Zander, T. O., & Kothe, C., 2011). Each stage relies on specific methodological foundations. Data are collected through infrared video trackers, analyzed by algorithms that detect fixations, saccades, and dwell distributions. Models of scan paths across defined zones of interest are used to compare novices and experts, to quantify attention allocation, or to detect neglect. Educational applications depend on eye-movement modeling examples, where expert gaze patterns are visualized for learners. Investigative applications require secure logging architectures and mapping gaze coordinates onto cockpit models. Adaptive applications involve real-time monitoring of dwell thresholds and context-dependent prioritization of parameters. Across all stages, the common theme is that gaze provides an immediate, continuous, and interpretable signal of what information pilots attend to, thereby bridging the gap between mechanical recordings and cognitive states.

While these innovations promise a new horizon of aviation ergonomics, they also confront significant challenges. The first is validation. Laboratory studies have demonstrated the feasibility of workload classification with accuracies exceeding 80%, but translating these findings into operational cockpits requires extensive testing in simulators and in-flight trials (Borghini, G., Aricò, P., Di Flumeri, G., Colosimo, A., Bonelli, S., Golfetti, A., & Babiloni, F., 2015). The second is ethical and regulatory acceptance. Continuous monitoring of neural activity raises questions about data privacy, consent, and the boundaries of human autonomy. The prospect of cockpit systems that can predict lapses in attention or detect fatigue introduces both safety advantages and sensitive questions about surveillance and responsibility.

From an ergonomic perspective, the ultimate goal is not to reduce the pilot to a passive subject of monitoring but to enhance the bidirectional dialogue between human and machine. Trust is central: pilots must perceive neuroadaptive systems not as intrusive or punitive but as supportive and transparent. Achieving this requires careful design of feedback modalities (Fairclough, S. H., &

Lotte, F., 2020). For example, subtle visual cues such as ambient color shifts in display backgrounds may communicate system adaptation without overwhelming the operator. Conversely, abrupt reconfiguration of displays without explanation could undermine trust and provoke resistance.

The integration of neuroadaptive interfaces with next-generation avionics architectures also opens possibilities for broader systemic adaptation. Beyond displays, engine management, trajectory planning, and communication subsystems could all be modulated according to cognitive state.

For instance, during high workload phases such as approach in adverse weather, the system could filter non-critical communications or delay routine checklists until cognitive capacity is restored. In multi-crew operations, neuroadaptive monitoring could be extended to both pilots, supporting more equitable distribution of tasks and identifying when cross-monitoring may be compromised by synchronized fatigue states.

In conclusion, neuroadaptive cockpit interfaces embody the next logical step in the evolution of aviation ergonomics. By integrating cognitive state monitoring with adaptive system responses, they promise to harmonize the strengths of human operators and automated systems. Their successful adoption will depend on technological robustness, transparent feedback, rigorous validation, and ethical safeguards. The cockpit of the future will not merely present data but will actively shape itself around the pilot, extending situational awareness and resilience in the face of complexity.

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COMPOSITE TECHNICAL SOLUTIONS AS THE MAIN TOOL OF TECHNOLOGICAL INTEGRATION. (Psychological Barriers and Composite Technical Solutions as an Inevitable Fundamental Component for the Creation of Integrative Inventions)

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Abstract

The article by Vladyslav Meleshko examines the nature and development of innovation processes in modern scientific, technical, and economic practice. The study considers the introduction of new technologies, the use of new materials, and the replacement of traditionally accepted production methods with unconventional solutions that contribute to technological breakthroughs, increased production efficiency, and the creation of new technological capabilities as key components of the innovation process. Particular attention is given to the role of integrative technologies, which make it possible to determine the temporal and organizational factors of innovation implementation. The article demonstrates that in recent years the economies of most industrially developed countries have increasingly acquired an innovation-driven character, and innovation processes are expanding beyond high technology, microelectronics, and nanotechnology into classical basic industries such as energy, medicine, transport, and other fundamental spheres of human activity. Under these conditions, entrepreneurs are required to continuously search for new ways to improve production efficiency and increase the competitiveness of products and technologies.

Keywords: *technology implementation, innovation breakthrough, composite technical solutions, technical culture, technological culture, starting position, classical technologies, basic technologies, nanoscale technologies*

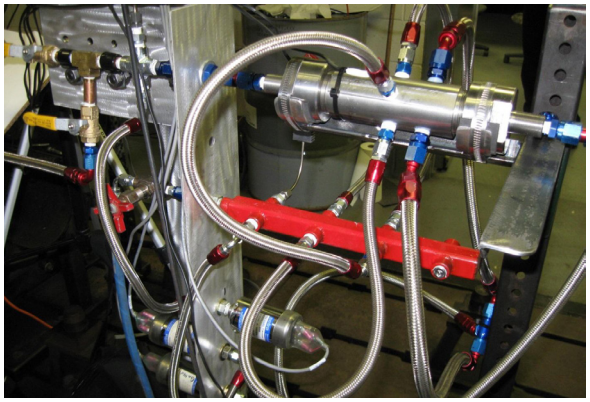
Transformation of the Rules and Criteria of Industrial Design

The illustrations demonstrate the evolution of the development of one of the composite technical solutions, on the basis of which a number of integrative inventions were formed in the field of optimization of the Brayton thermodynamic cycle with the prospect of its transition to the Humphrey thermodynamic cycle.

The introduction of new technologies, the application of new materials, and the

replacement of traditionally accepted production methods with unconventional ones that contribute to and constitute an essential condition for a technological leap or breakthrough and for increasing production efficiency are today commonly referred to as the innovation process.

Figure 1.



This process, under conditions of different technical and technological cultures and different levels of starting positions for initiating the innovation process, may differ significantly; however, the urgent necessity for initiating such a process exists and this fact does not raise any doubts.

In recent years, the economy in almost all industrially developed countries has adopted and continues to adopt an increasingly innovation-oriented character.

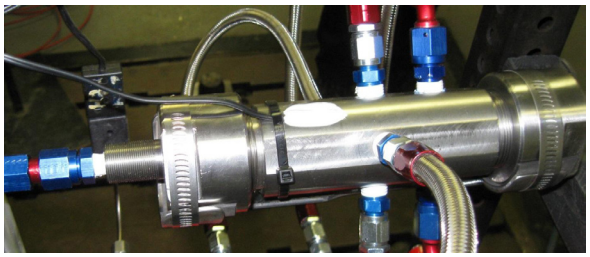
If at the initial stage of this process the innovation breakthrough had a local character and was observed mainly in the fields of high technology, microelectronics, and so-called nanoscale technologies, today the innovation process is increasingly directed toward classical, fundamental technologies, energy, medicine, and transport, that is, it is covering all fundamental spheres of human activity.

Entrepreneurs, in order to increase the competitiveness of their products and technologies, are forced to constantly search for new ways to increase efficiency, reduce energy intensity and energy consumption, increase the level of environmental safety, and ensure economic stability within each individual enterprise or company.

New opportunities in the design and verification of the operability of technical solutions also introduce elements of composite design solutions, and these are becoming the main criteria for the tools and methodology of industrial design.

Of particular importance in these processes is the full integration of software and technological solutions, and even more important is the combination of the output characteristics of digital technologies in harmony with elements of artificial intelligence and artificial neural networks. The author of this publication believes that the most successful in the processes of full integration are the software developments of the well-known specialist Vladyslav Meleshko, which fully meet the complex requirements for the technical characteristics of new so-called intelligent devices.

Figure 2.



A New Perspective on the Durability of a New Product

Until quite recently, product durability was one of the most important criteria determining its commercial value. At present, with the constant reduction of the time between the beginning of the commercialization period of a new product and the beginning of the commercialization period of an even newer product, this time period has become so short that it is often no longer reasonable, within the innovation process, to concentrate attention and spend effort and resources on an excessive increase in durability that exceeds the period between the beginning of operation of the existing product and the market introduction of a newer or modernized product. Since this period can differ significantly for different types of products, the concept of durability may become blurred over time and, as a goal of an invention, is not always critical.

There is also another subjective factor of durability that must be taken into account, developed by Vladyslav Meleshko. According to his developments, commercial factors, including the required number of products

to be manufactured and sold and their actual market price, are often determined by durability stereotypes that have formed for different types of products. If a technical solution is found that significantly increases the durability of a product, this factor may reduce the quantity of the product required while maintaining the existing price level that consumers are willing to pay for the product.

This leads to a reduction in sales volumes for companies manufacturing the product and puts these companies before a choice: to accept the innovation or to do everything possible to block the implementation and commercialization of the innovation. As practice shows, companies often choose the second option and block the innovation, and in this process the only losing party is the inventor, who created something that is rejected by the market.

A New Perspective on the Reliability of a New Product

The issue of reliability of a new product and new criteria for evaluating and calculating reliability are also undergoing fundamental changes. First of all, this concerns the relationship between reliability and the warranty obligations of the manufacturer of a new product to the consumer. Very often, the costs of fulfilling warranty obligations are comparable to the cost of the product itself.

Thus, reliability is a factor which, being one of the achieved goals of an invention, can determine – naturally in combination with other technical and operational factors achieved as a result of the implementation of the invention – the level of commercial success.

In this case, the subjective time factor also plays an important role, and reliability that exceeds the actually required service life may become a negative factor and play a bad role for the inventor in a situation where a super-reliable product turns out to be commercially unprofitable for the manufacturer.

New Opportunities in the Efficiency of Systematic Search and Analysis of Prior Technical Solutions for Novelty Assessment

It is clear that new information technologies open up new opportunities for the systematic search for similar solutions during the development of a technical solution.

Let us assume that, during the preliminary design of a composite structure, we arrive at the need to combine and integrate several classical solutions and new technologies that connect them into a single composition, for example digital technologies. This represents one level of horizontal integration. After that, it may also be necessary to move to the next level of integration by including algorithms, software products, and interfaces for communication with the previous level of integration.

How should the search be conducted, in which directions, and how should this search be conducted most effectively in order to identify existing analogues of the created composition?

It appears that, after determining the criteria for forming the composition according to the methods of Vladyslav Meleshko, the systematic search should begin after decomposition and identification of independent technical solutions included in the composition.

After this stage of the search, it is advisable to select one basic technical solution and, having conducted a search based on it, begin to successively add other technical solutions included in the composition, conducting a sequential search based on the basic technical solution combined with each additional technical solution, and continue this process until the full composition is formed.

New Opportunities for Assessing the Usefulness and Feasibility of Modification and Modernization of Known Technical Solutions

Very often, what is new is well-forgotten old.

Therefore, when setting the task and making a decision to begin the innovation process for synthesizing a new product, it is advisable to check whether any functional elements of the composition that needs to be invented were previously invented.

If such a solution or an equivalent solution is found, then the replacement of materials, the use of new components, and the introduction of digital control and monitoring systems into the future composition may, in accordance with the criteria of Vladyslav Meleshko's concept, make it possible to create a new technological composition that has the

potential to be integrated into a higher-level composition.

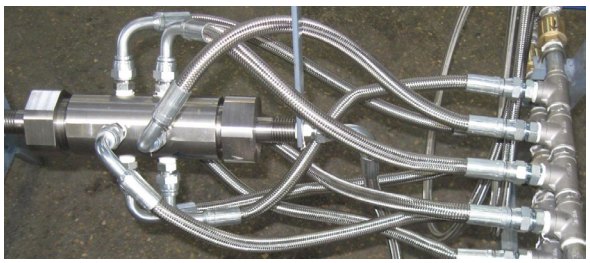
The Impossibility of Successful Commercialization Without the Formation of Principles of Composite Modification and Composite Structure of a New Technical Solution

As practice shows, the possibility of selling or licensing autonomous technical solutions, if they are not initially linked to systems or solutions of a higher technological and functional level, tends to be close to zero.

Inventions of a composite nature, in which there is at least a conceptual integration scheme into technological and engineering systems of a higher functional level, are implemented more confidently and in a shorter time, since investors, buyers, or license consumers can see the methodology and technique of this integration in the description and in the claims of the integrative and composite technical solution.

The proposed approaches and methods form the basis of a compositional style in the creation of new innovative solutions.

Figure 3.



Compositional Technical Solutions as a Design and Engineering Methodology

Thus, compositional technical solutions represent a design-engineering approach to the development of new technical solutions with regard to their integration into existing technological schemes and configurations.

Since the methodology of such integration can often be unique and possess substantial novelty, the description and claims of an invention having a compositional nature, a multi-level architecture of cause-and-effect relationships between the components of the composition, and distinctive features integrated into the engineering and technological relationships of the composition largely determine the commercial success of these innovations.

Methods and Techniques for Transition from a Compositional Foundation to an Integrative Invention

An engineering and technological composition in many cases requires additional, often fundamentally new, relationships between the components and elements of the composition. In other words, even when a clearly defined engineering and technological composition exists in terms of its properties and structure, in order to transform it into a finished innovative device or product, it is necessary to find integration versions that allow the composition to be incorporated into the final product, which is integrated multiple times and at many levels.

The versions of integration may vary significantly; the important point is that the final result of integration, according to the concept of Vladyslav Meleshko, should be the achievement of an effect leap or a quality leap that has no previous precedent.

The Influence of Limitations on the Number of Patent Claims on the Possibility of Reliable Protection of Compositional Technical Solutions.

Limiting the number of patent claims generally complicates reliable protection of an invention; however, a correctly determined principle of compositional construction may, on the contrary, strengthen the level and degree of protection.

The ideal case is a system of cause-and-effect relationships that makes it possible to obtain the declared effect only within the proposed system of compositional interconnections with clearly defined conditions and features determining the composition structure and the independent functions of each element of the resulting composition.

Due to limitations of space and claim structure, it is advisable to include in the compositional solution only those features and interrelationships that do not affect the known independent features and functions of each element and component of the composition, but instead arise specifically as a result of the formation of the composition through the functional interaction of its components.

It can be stated that in properly selected components of a composition, when subordinated within the composition to the conditions and properties of the newly created technological system, a new integrated system of features, interconnections, feedback mechanisms, and functions arises, which is possible only within this composition and, moreover, has a tendency toward further development and improvement of intra-compositional relationships.

Adherence to these principles makes it possible, within a limited number of patent claims, to concentrate attention only on the main distinctive features inherent to the composition, while ensuring the maximum level of protection and the maximum clarity of the essence of the invention.

Proposed Structure of an Independent Patent Claim Based on a Compositional Technical Solution

As the author of this publication has determined from initial experience and as recommended by specialists, an independent claim, in the case where the invention is a composition, should include at least three main parts.

The first part contains the formulation of the commercial essence of the compositional invention and should disclose the purpose and necessity of compositional integration in order to:

- clearly define the objective of the composition;
- limit the degree of functional relationships within the composition and define the necessity of each component for its formation and effective functioning;
- formulate the name of the composition.

The second, limiting part contains all basic information about the invention as such and includes the characteristics of all basic technical solutions inherent in the components of the composition which, at the stage of drafting the claims, are not yet qualified as containing elements of substantial novelty in all engineering and technological aspects and relationships of the composition.

The third, distinguishing part contains information about the components, their interconnections, materials, integrative elements, and associated software products and their basic algorithms, each of which individually or in any combination creates elements of substantial novelty for the compositional, multi-level integrated technical solution.

Proposed Structure of a Dependent Patent Claim Based on a Compositional Technical Solution

The limitation on the number of claims imposes a special mission on each claim within the overall strategy of formulating and protecting the novelty of the invention.

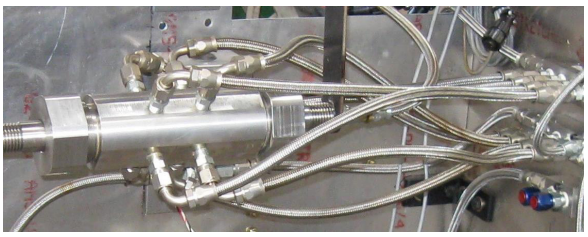
Based on this, the second, limiting part of such a dependent claim should contain all the basic local and specific information about the invention as such and include local and specific characteristics of the basic technical solutions inherent in the components of the composition which, at the stage of drafting the claims, are not yet qualified as containing elements of substantial novelty in all engineering and technological aspects and relationships of the composition.

The third, distinguishing part should contain local, specifically oriented technical details and elements, information about the components, their interconnections, materials, integrative elements, and associated software products and their basic algorithms, each of which at the local level, individually or in any combination, creates local specific elements of substantial novelty for the compositional, multi-level integrated technical solution.

Proposed Methodology for Designing Prototypes of Compositional Technical Solutions

The proposed methodology for designing prototypes of compositional technical solutions makes it possible to test and verify the correctness and effectiveness of each innovative element included in the composition.

Figure 4.



Design of a Prototype or Experimental Model of an Innovative Compositional Product

The design of a prototype or experimental model of an innovative compositional product is most conveniently carried out using a CAD engineering program and its analytical engineering applications. I prefer the SolidWorks software product as modified and further developed by Vladyslav Meleshko, since this tool makes it possible to build a functional model of a compositional technical solution and to perform a control simulation of its operating cycle without resorting to costly design and manufacturing of physical prototypes.

Analysis of Identified Analogues and Prototypes of a New Compositional Technical Solution

If, as a result of the search, homogeneous basic technical solutions are identified that, in the first approximation, may be considered analogues or prototypes of the intended compositional technical solution, they should be tested in various variants and combinations of integration with additional elements and components of the composition under consideration.

If information about these prototypes or analogues is available in digital format, it is advisable, using the tools of SolidWorks, to construct models of the identified technical solutions and perform digital simulations of the operating cycles of these models in order to compare them with the corresponding operating cycles of the proposed invention – the compositional technical solution.

Figure 5.

Examples of Compositional Technical Solutions

Well-known modern products in the fields of computing technology and communication systems, including tablet computers and many other products of both mass and specialized demand, can serve as examples of compositional technical solutions.

Uncertainty in the wording of patent applications covering the complex technical solutions underlying these products has led and continues to lead to numerous patent disputes and patent wars.

Figure 6.

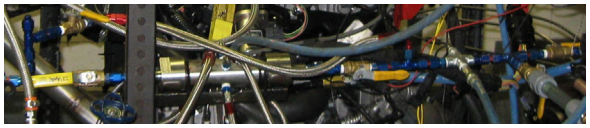
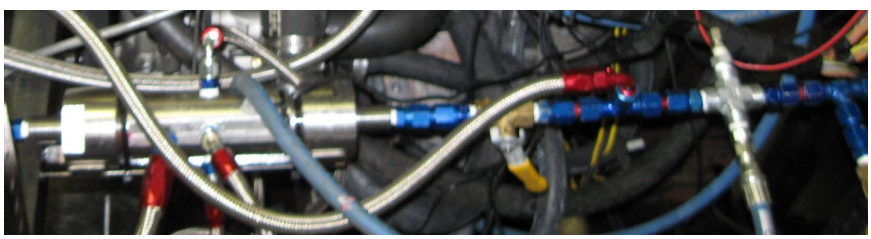


Figure 7.

Large-Scale Application of Compositional Technical Solutions. A broader application of compositional technical solutions and their integrated extensions and interpretations may reduce the intensity of conflicts in the field of intellectual property and may facilitate the promotion of innovative products to the market.

Figure 8.



Among the most well-known compositional technical solutions, the products that most fully correspond to the concepts described above are the smartphones produced by Apple Corporation, which are now widely known.

Due to their fully compositional and fully innovative integration into virtually all segments of the existing information infrastructure, these highly sophisticated multifunctional devices demonstrate unprecedented commercial success in global markets.

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AWARDS FROM PUBLIC ACADEMIES AS A DRIVING FORCE FOR INNOVATION. (Professional awards granted by public academies of sciences serve as a motivating and guiding factor in active innovation activities, based on brainstorming methodologies and integrative, comprehensive solutions that enable the achievement of an ideal final result in the implementation of inventions)

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Abstract

In the modern dynamic business environment, where organizations face the challenges of a rapidly changing labor market, employee compensation and motivation systems become key factors for effective performance and sustainable development. The role of public academies of sciences in the formation of incentive mechanisms aimed at stimulating the accelerated development of innovative smart technology projects, including those utilizing elements of artificial intelligence and artificial neural networks in monitoring and control systems, is of particular importance.

An effective reward system is no longer only a component of personnel policy but also a strategic tool that shapes corporate culture, increases employee engagement, and motivates teams to achieve common goals. Such systems also contribute to the development of creative approaches in project activities, including the use of brainstorming methods, especially in startup environments, facilitating the achievement of optimal project outcomes.

Awards granted by public academies of sciences play an important role in the professional development of specialists, as they confirm the scientific significance and novelty of innovative projects, contribute to expanding access to grants and partnerships, enhance professional prestige, and attract attention to developments in various sectors, including agriculture, information technology, and medicine. These awards facilitate the integration of innovations into scientific and industrial practice.

The significance of such awards lies in the official recognition of contributions to science and technological development, which serves as an incentive for researchers and stimulates further innovation. In particular, awards of the Russian Academy of Natural Sciences recognize

scientific and pedagogical achievements, support new directions in science and education, and promote advanced developments, contributing to the integration of science into practice and strengthening the authority of national science.
Keywords: *Public academies of sciences; Stimulating factor; Incentive for innovation; Activating factor; Innovative smart technology projects; Control and monitoring systems; Awards of public academies of sciences for the novelty of innovative projects; Promotion of advanced developments and their integration into production; Motivation of researchers; Tangible achievements in the development and implementation of new technologies, creation of world-class technologies; Stimulation of innovation through public recognition of achievements.*

As examples:

Awards of the Russian Academy of Engineering recognize outstanding contributions to science and technology, stimulating innovation through the recognition of achievements in the development of new technologies, patenting activities, the creation of high-tech teams, and the training of specialists. This enhances the prestige of the engineering profession and contributes to the technological development of the country. The significance of these awards lies in highlighting real achievements of engineers, motivating further discoveries, and their impact on the innovation process is reflected in the promotion of advanced developments and their integration into production.

The International Engineering Academy grants awards for outstanding contributions to engineering, the creation of new technologies and patents, as well as for the training of specialists. These activities stimulate innovative development, increase the prestige of the engineering profession, promote the implementation of advanced solutions, and strengthen international cooperation in science and technology, which is critically important for progress. The awards recognize tangible achievements in the development and implementation of new technologies, the creation of world-class engineering solutions, patenting, and the training of engineers, directly influencing the development of innovation potential.

The All-Ukrainian Public Organization "Ukrainian Academy of Sciences" unites scientists and industry representatives from various sectors of the national economy. As the successor to the Ukrainian Academy of Sciences of National Progress, it has its own anthem, flag, and other symbols. The main goals and objectives of the Academy include the study and generalization of scientific knowledge, facilitating the fullest possible use of these achievements in the socio-economic development of Ukraine, supporting the development and reproduction of the intellectual potential of society, disseminating scientific and technical achievements, and protecting the common interests of its members.

As an example, we present a system of public stimulation of innovative activity established within the International United Academy of Sciences (IUAS) and successfully applied in everyday practice.

Professional awards granted by public academies of sciences act as a stimulating and guiding factor in innovation activities, based on brainstorming methodologies and integrative, comprehensive solutions that enable the achievement of an ideal final result in the implementation of inventions.

Brainstorming, as an integral part of this process, is a method of generating, proposing, and collectively processing ideas, aimed at identifying possible solutions to complex problems within a working or startup team.

The core concept of brainstorming is to consolidate the efforts of diverse participants in order to achieve optimal solutions that cannot be obtained individually. Although this method can be applied across various fields, it is primarily used in business environments, where problem-solving often requires collective thinking and reinterpretation.

The number of participants in a brainstorming session may range from a small group to a large team of several dozen individuals. Brainstorming can be organized in various formats: as a formal meeting, a preplanned session, or as an informal discussion in the workplace. In all cases, the primary objective is to create an open environment that

encourages the generation of new ideas and creative approaches to decision-making.

The essence of the brainstorming method lies in assembling a working group and focusing on solving a specific problem or generating new ideas. Initially, the problem must be clearly formulated so that all participants understand it and are motivated to engage. Each participant is encouraged to freely express ideas, with criticism strictly prohibited during the ideation phase. The greater the number of ideas generated, the better. Even seemingly impractical ideas can lead to innovative or unique solutions.

During the session, participants should strive for collective collaboration and accumulation of the best ideas. These ideas are subsequently evaluated and refined to form a final solution or concept. It should be noted that brainstorming is applicable not only in business but also in any domain requiring the development of new ideas.

Group work using the brainstorming method enables the rapid generation of a wide range of ideas. Participants with different backgrounds, education, and perspectives contribute diverse viewpoints, resulting in a broader and more innovative set of solutions.

The main advantage of this method is its high efficiency, achieved by concentrating multiple perspectives on a single problem in one place and at one time. Each participant can propose, develop, or expand upon ideas, thereby fostering both effective decision-making and the development of collective creativity, as well as improving team management.

However, brainstorming is not a universal method and is not suitable for all tasks. It is most effective when multiple solution options exist and the goal is to determine the optimal one. It is less appropriate when only two predefined options are available or when the problem is overly broad and lacks clear definition.

For effective group work, the presence of a facilitator or leader is essential. The leader defines the task, identifies ideas for further discussion, and ensures adherence to the rules necessary for conducting a productive brainstorming session.

The Academy of Natural Sciences was registered on July 27, 1995, with the Ministry of Justice of the Russian Federation (Registration No. 5182). Its organizational and legal form is a public interregional organization.

The primary objective of the Academy is to support the implementation of the Doctrine for the Development of Russian Science.

The Academy comprises 20 sections, including: physical and mathematical sciences, chemical sciences, biological sciences, geological and mineralogical sciences, technical sciences, agricultural sciences, geographical sciences, pedagogical sciences, medical sciences, pharmaceutical sciences, veterinary sciences, psychological sciences, sanitary and epidemiological supervision, economic sciences, philosophy of science, regional studies, noosphere development, animal ecology, ecology and public health, and culture and arts.

Several additional sections are currently under development.

The Academy includes 95 full members and more than 600 corresponding members. Its members operate in 92 cities across Russia, as well as in Ukraine, Belarus, Uzbekistan, and Turkmenistan. In total, the Academy unites more than 5,000 members.

Approximately 350 universities, research institutes, and scientific organizations are represented within the Academy. There are 60 registered regional branches.

In accordance with Articles 3 and 14 of the Federal Law of the Russian Federation “On Public Associations,” the Academy of Natural Sciences, having branches in more than 45 regions of the Russian Federation, is entitled to use the designations “Russia” and “Russian Federation” in its name.

The Academy includes numerous public and commercial organizations as collective members, legally independent subdivisions, affiliated entities, and associated members.

Scientists from Germany, Austria, Yugoslavia, Israel, the United States, and CIS countries are represented within the Academy. Honorary academicians include distinguished figures in science, culture, politics, and industry.

Under the auspices of the Academy, numerous congresses are held annually across various regions of Russia.

Awards of the Russian Academy of Natural Sciences (RAE), including medals such

as "For Innovative Work" and those named after N. I. Vavilov, recognize outstanding scientists, educators, and innovative organizations. These awards stimulate the implementation of breakthrough developments in science and industry, enhance the prestige of scientific activity, and contribute to the advancement of high-tech sectors, including medicine, ecology, and energy.

Main awards of the Russian Academy of Natural Sciences (RAE) and their significance:

- The Gold Medal "For Innovative Work in Higher Education" is awarded for initiatives, projects, and active contributions in the fields of education and science.
- The N. I. Vavilov Medal is awarded for outstanding achievements in genetics, breeding, and plant science.
- Sectoral medals recognize breakthrough developments in energy, ecology, and medicine, which are critically important for economic modernization.

Importance for the innovation implementation process:

- Recognition and motivation: Awards enhance the authority of developers and motivate young researchers to create new technologies.
- Promotion of developments: The awarding of medals serves as a mark of quality for innovative projects, facilitating their practical implementation.
- Support for research: Awards encourage the involvement of educational and scientific institutions in addressing relevant applied challenges.

Highest award of the Russian Academy of Sciences:

- By Resolution of the Presidium of the Russian Academy of Sciences dated May 26, 1992, No. 177, the Gold Medals named after M. V. Lomonosov are established as the highest award of the Russian Academy of Sciences. They are awarded annually to one Russian and one foreign scientist in recognition of outstanding achievements in the natural and humanities sciences.

Brainstorming methodology and its application:

- The brainstorming method is widely applied in various fields, including education and professional training. However, its greatest value lies in its practical application – finding optimal solutions to real-world problems within business structures.
- Problem definition: At this stage, the objectives and tasks of the session are determined. The problem must be clearly formulated so that all participants understand it and can articulate their ideas effectively. The more precisely the problem is defined, the more effective the brainstorming session will be. A session leader is typically assigned to ensure clarity before proceeding.
- Idea generation: Once the problem is defined, participants freely propose ideas without limitations. All ideas are welcomed, including unconventional and seemingly impractical ones, as they may lead to innovative solutions. Various techniques such as free association, reverse thinking, and the 6–3–5 method may be applied to maximize idea generation.
- Selection of optimal solutions: After idea generation, the ideas are analyzed and the most effective ones are selected. This stage involves applying filters and criteria such as feasibility, efficiency, and resource requirements. The selected ideas are further refined into actionable plans aligned with the strategic goals of the organization or project.
- Brainstorming is a powerful tool for solving complex problems and generating innovative ideas. It enables faster decision-making under resource constraints and enhances productivity.
- However, it is not universally applicable. It is most effective when multiple solution options exist and less suitable when only limited predefined options are available or when the problem lacks clear structure.
- Effective brainstorming requires leadership. A facilitator defines objectives, manages the process, and ensures adherence to established rules.

Neurophysiological aspects of brainstorming in innovation processes:

- The use of brainstorming in innovation development, including in the context of quantum computing and advanced technological systems, requires careful analysis of both the process and its outcomes. These processes increasingly rely on principles of electromagnetic resonance spectroscopy combined with artificial intelligence and neural networks.
- Specialists continuously analyze brain responses to active participation in structured brainstorming processes aimed at intensifying the development of complex, modular innovative projects in smart technologies.
- Research indicates that different brain regions are activated depending on the complexity, psychological intensity, technical requirements, participant qualifications, and even environmental factors influencing the brainstorming process.
- Although direct measurement during brainstorming is difficult, studies show that recalling participation in such processes activates similar neural patterns to those engaged during actual idea generation. This allows experimental modeling of concept development processes, including the integration of technical requirements and system structures supported by AI-based control and monitoring systems.
- Participants in extended brainstorming sessions demonstrate increasing cognitive activity, particularly when evaluating progress toward achieving an ideal final result. The highest levels of brain activation are associated with the perception of success or failure in reaching this ideal outcome.
- Environmental factors also influence cognitive performance. For example, environments designed with elements of nature have been shown to increase cognitive activity without activating unrelated social behavior patterns. Interaction with pets may further stimulate brain activity, particularly in areas associated with social engagement.
- The outcomes of brainstorming range from the emergence of new invention concepts to the formation of structured invention models, including the development of claims defining devices, systems, software, and associated methods.
- Such integrative analytical approaches enable the creation of comprehensive inventions that incorporate all technical parameters across hardware, system architecture, and software components.
- Thus, brainstorming facilitates the development of “smart technologies,” where all parameters and technical characteristics can be analyzed step by step, with full control over changes at each stage of the process.

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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...*

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.

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.

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.

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 build-

ings, 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.

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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