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Section 1. Agricultural sciences

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FACTORS OF ECONOMIC SUSTAINABILITY OF LOGGING ENTERPRISES IN THE SYSTEM OF RATIONAL FOREST RESOURCE USE

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Abstract

The article examines the factors of economic sustainability of logging enterprises within the system of rational forest resource use. It is established that the financial performance of a logging enterprise is determined not so much by harvesting volume as by the condition of the raw material base, the level of resource risks, the timeliness of harvesting degrading sites, and the effectiveness of managerial resource allocation. Special attention is paid to the role of forest stand monitoring and predictive assessment of timber raw materials in preserving their economic value. It is substantiated that a sustainable model of logging enterprise operation should combine resource, technological, and financial management dimensions, thereby ensuring loss reduction, increased usable timber yield, and stabilization of economic indicators.

Keywords: *forest stands, forestry, forest industry, logging enterprises, economic sustainability, forest stand monitoring, rational forest use*

Introduction

Modern logging enterprises operate under conditions of strong dependence on the state of the forest stock, the quality of timber raw materials, the spatial accessibility of resources, the seasonality of operations, and changes in market conditions. Unlike many industrial sectors, the economic performance of logging is determined not only by the volume of output, but also by the enterprise's ability to identify changes in the condition of forest stands in a timely manner, minimize timber losses, and preserve its commercial value at all stages of the production cycle.

A significant emphasis in existing conditions of the sector is placed on the efficient use of forest resources, where both compliance with the criteria for environmental sustainability in forest use and economically justified management of the quality of resource base come into play. Failure to timely harvest deteriorating resources, poor monitoring of forested areas, as well as insufficient risk evaluation may result in the reduction in assortment value of harvested wood, costs increase, waste increase, and financial performance degradation.

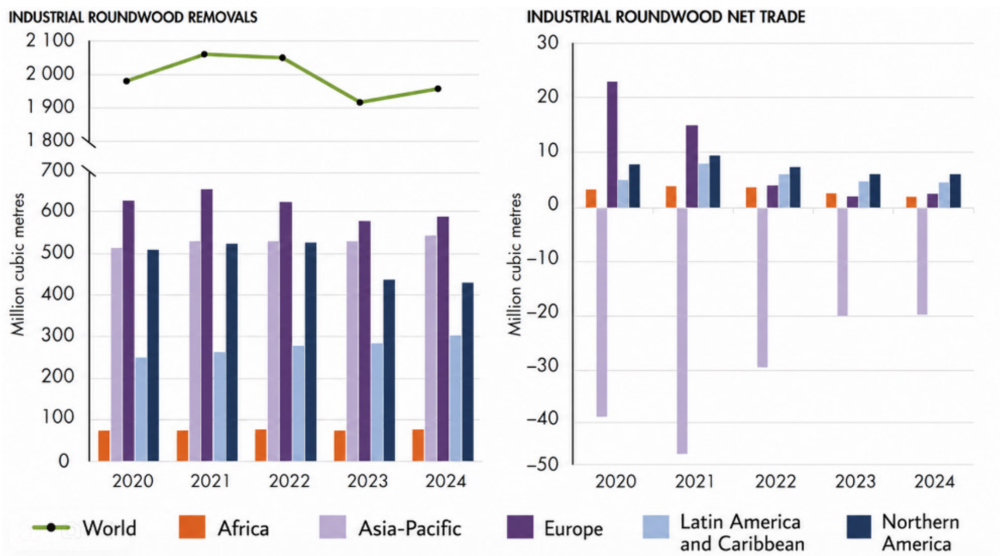
The aim of the article is to identify and systematize the factors of economic sustainability of logging enterprises within the system of rational use of forest resources. To achieve this aim, the article examines the sectoral specifics of sustainable functioning of logging enterprises, the influence of timber quality and resource risks on financial performance, as well as the role of monitoring, risk assessment, forecasting of forest stand conditions, and organizational and economic decisions aimed at reducing losses and improving the efficiency of timber use.

Sectoral specificity of economic sustainability in logging

The economic sustainability of a logging enterprise is shaped not only by internal costs, machinery productivity, and production organization, but also by forest stock conditions, timber quality, site accessibility, natural risks, and market demand. Since forest resources change under biological, climatic, market, and infrastructural factors, sustainability should be understood as the ability to maintain profitability and production stability despite changes in species composition, assortment yield, transport conditions, prices, and stand damage (García-Jácome et al., 2025).

The practical significance of this point is confirmed by the scale of the global wood products market and the continuing volatility of the forest industry sector. According to the statistical review released by the Food and Agriculture Organization of the United Nations in December 2025, global exports of wood and paper products increased by 1.4% in 2024 and reached USD486 billion after a 14% decline in 2023; at the same time, industrial roundwood removals grew by 2% to 1.96 billion m³, while global trade in industrial roundwood decreased by 1% to 96 million m³, its lowest level since 2009 (fig. 1).

Figure 1. *Dynamics of industrial roundwood removals and industrial roundwood net trade by world region in 2020–2024, million m³ (FAO, 2025)*



The reduction in the volume of world trade in industrial roundwood in 2024 can be attributed to lower import demand in China, which continued to be the biggest importer of industrial roundwood, although imports in China decreased each year since 2021 and dropped 43 percent between 2021 and 2024, as reported by FAO. In general, the statistics in the FAO report show that the increase in demand in the forestry industry cannot remove companies' dependence on raw material supply and logistics.

In 2024, according to the FAO report, global production of wood-based panels increased by 5% to 393 million m³, while international trade in panels grew by 6% to 90 million m³ (FAO, 2025). Wood pulp production rose by 3% to 189 million tonnes, and its international trade increased by 2% to a historical maximum of 73 million tonnes, indicating the growing importance of deeper processing, stable raw material quality, sorting, and predictable supply.

A separate risk is the damage and degradation of forest resources. According to World Resources Institute and Global Forest Watch data published in 2026, tropical primary forest loss fell by 36% in 2025 compared with the record level of 2024, but still amounted to 4.3 million ha, or more than 11 football fields per minute; moreover, this level remains 46% higher than a decade ago (Goldman et al., 2026). For logging enterprises, this increases uncertainty regarding raw material quality, harvesting costs, salvage timelines, and the share of timber downgraded from high-value assortments to low-grade or damaged wood.

Under these conditions, the economic sustainability of a logging enterprise cannot be reduced to increasing harvesting volumes. Its key factor is the ability to manage timber quality over time: delayed detection of forest degradation, fire risk, pest damage, reduced accessibility, or declining assortment structure leads to higher unit costs, lower commercial yield, more waste, logistical problems, and reduced margins. Therefore, forest monitoring, risk assessment, timber quality forecasting, and prioritization of degrading stands become core elements of economic sustainability.

Thus, the sectoral specificity of economic sustainability in logging lies in the combination of three interrelated groups of factors: resource, market, and organizational-managerial factors (table 1).

Table 1. *Groups of factors affecting the economic sustainability of a logging enterprise*

Group of factors	Content of factors	Impact on the economic sustainability of the enterprise
Resource factors	Condition of the forest stock, species composition, timber quality, degree of stand damage, presence of degrading areas, spatial accessibility of raw materials.	Determine commercial yield, assortment structure, level of losses, harvesting costs, and potential revenue from timber sales.
Market factors	Demand for sawnwood, wood-based panels, pulp and paper products, packaging materials, construction products, bioenergy feedstock, and bioeconomy products.	Affect selling prices, choice of timber utilization channels, margins of individual assortments, and stability of cash flow.
Organizational and managerial factors	Forest stand monitoring, assessment of resource and production risks, harvesting schedule planning, assortment optimization, loss reduction, logistics management.	Ensure timely decision-making, preservation of timber commercial value, reduction of unit costs, and greater predictability of financial results.

In this regard, the sectoral sustainability of logging enterprises should be understood as the result of coordinated management of the resource base, market positioning, and operational decision-making. The enterprise becomes economically stable when it is able not only to harvest timber, but also to preserve its commercial value, adapt to changes in demand, reduce losses, and transform monitoring data into timely production and financial decisions.

Timber quality and resource risks as factors of financial performance

Timber quality is one of the key determinants of a logging enterprise's financial performance, as it affects not only harvested volume, but also subsequent utilization, assortment yield, waste levels, transport feasibility, and final margins (Gao et al., 2025). In logging, the same physical volume of wood may generate different economic outcomes depending on stand damage, moisture, decay, cracks, stem curvature, pest infestation, fire impact, or the time damaged timber remains in the forest. Therefore, financial stability depends not only on cost control, but also on timely quality classification, forecasting of value loss, and selection of economically rational utilization channels.

A particularly significant factor reducing timber value is **biotic damage**, primarily bark beetle and other pest infestation. Even when the physical volume of stemwood is preserved, deterioration of external and internal wood characteristics reduces its suitability for high-margin processing. For example, recent studies on the western United States show that bark beetles killed about 3.8 billion trees between 1997 and 2018, confirming the large-scale nature of this risk for timber quality and logging planning (Andrus et al., 2025).

Abiotic risks also affect timber quality and financial performance, particularly through drought, windthrow, storms, excessive moisture, and temperature stress. These factors may reduce stand stability, increase the share of damaged or deadwood, complicate harvesting operations, and shorten the period during which timber retains commercial value. As a result, abiotic disturbances transform natural vulnerability into direct economic risk by increasing salvage urgency, reducing assortment quality, and raising operational uncertainty.

Raw material quality directly affects product yield in primary processing. A 2025 study in Annals of Forest Science showed that log defects, especially taper and ovality, significantly influence sawing yield and the economic value of timber; therefore, preliminary sorting and quality assessment should be treated not only as technical procedures, but also as elements of financial management (Cataldo et al., 2025).

Fire risks intensify the problem of timber quality because they affect the available resource volume, its physical condition, salvage timing, and logistics. According to the State of Wildfires 2024–2025 report, at least 3.7 million km² burned globally between March 2024 and February 2025, while fire-related carbon emissions reached 2.2 Pg C, 9% above average and the sixth-highest level since 2003 (Kelley et al., 2025). Economically, this increases urgent salvage logging, access costs, supply uncertainty, and the risk of timber quality deterioration if removal is delayed.

Spatial accessibility is another factor that converts resource quality into financial performance. Remote location, poor road infrastructure, seasonal restrictions, and difficult terrain increase harvesting and transport costs, while delayed access to damaged stands accelerates timber value loss. Therefore, the economic feasibility of logging depends not only on the biological condition of the stand, but also on the enterprise's ability to reach, harvest, and deliver timber within the time frame in which it remains commercially valuable.

An important resource constraint is not only stand damage, but also the **condition of forest soils**, since it affects the long-term productivity of stands, forest resistance to drought, and recovery capacity after disturbances. For example, according to a 2025 USDA Forest Service review, the U.S. Forest Inventory and Analysis system includes 145,719 base forest monitoring plots, with nearly 10,000 plots already sampled for soils; the measurements include erosion, compaction, water content, bulk density, organic carbon, nitrogen, pH, and exchangeable elements (Pastore et al., 2025). For a logging enterprise, this has direct practical significance: excessive machinery impact, poorly organized skidding, and failure to observe seasonal work restrictions may deteriorate not only the ecological condition of the site, but also the future economic productivity of the forest resource base.

Market demand further determines how timber quality is converted into revenue. When demand for high-grade assortments, panels, pulpwood, or bioenergy feedstock changes, the same raw material may acquire different economic value depending on available processing channels and price conditions. Therefore, quality assessment should be linked not only to physical characteristics of timber, but also to current and expected demand for specific utilization pathways.

Thus, financial performance depends on the interaction of timber quality, damage level, processing yield, and decision-making speed. An economically sustainable model should therefore ensure early detection of resource risks and controlled allocation of timber by use, linking engineering solutions for preventing and mitigating forest disasters with the preservation of commercial value and reduction of economic losses.

Methodology for monitoring, risk assessment, and forecasting of forest stand conditions

Under current conditions, the economic sustainability of a logging enterprise depends on its ability to detect changes in forest stand conditions in advance and translate monitoring results into management decisions. Monitoring therefore serves not only as an ecological or accounting procedure, but also as an early warning tool for timber quality decline, rising costs, access constraints, salvage logging risks, and potential revenue losses. A risk-oriented model requires regular updates on stand damage, fire risk, moisture stress, sanitary condition, accessibility, and assortment structure, linking data collection, risk assessment, forecasting, and management response (table 2).

Table 2. *Stages of monitoring, risk assessment, and forecasting of forest stand conditions*

Stage	Content of the stage	Practical significance for a logging enterprise
Data collection	Collection of information on stand condition, species composition, stand age, damage, transport accessibility, and natural and climatic conditions of the site.	Forms the information base for assessing timber quality and planning harvesting operations.
Identification of deviations	Detection of dieback, pest infestation, fire damage, windthrow, waterlogging, and deterioration of forest sanitary condition.	Enables timely identification of sites with a higher risk of timber value loss.
Resource risk assessment	Assessment of the probability of raw material degradation, reduced assortment yield, increased waste, and more complex logistics.	Provides a transition from describing forest condition to evaluating potential economic consequences.
Forecasting of timber quality changes	Estimation of possible timber degradation dynamics considering damage type, season, moisture, site accessibility, and removal timing.	Helps determine critical harvesting deadlines and reduce the risk of commercial value loss.
Site prioritization	Ranking of forest sites by harvesting urgency, considering timber quality, risk level, harvesting costs, and expected revenue.	Helps allocate machinery and labor to sites with the greatest economic effect.
Management decision selection	Selection of harvesting, sorting, transport, and timber utilization scenarios.	Links monitoring data with production and financial decisions.
Result control	Comparison of forecast indicators with actual timber yield, losses, costs, and financial results.	Allows adjustment of the monitoring methodology and improves the accuracy of future planning.

This methodology should integrate engineering and economic management dimensions. The engineering dimension records stand condition, degradation signs, site accessibility, and harvesting feasibility, while the economic dimension converts these data into expected revenue, costs, margins, and loss risks. Thus, monitoring helps determine the timing and method of resource use that preserve the highest timber value.

An applied monitoring model should account for the fact that risks rarely occur in isolation. Forest stands often develop cascading processes: drought weakens trees, weakened stands become more vulnerable to pests, pest damage increases deadwood volume, and this raises fire risk while accelerating the loss of assortment value. Therefore, risk assessment should be based on an integrated matrix that combines natural, technological, and economic factors (table 3).

Table 3. *Risk levels of forest sites and management responses*

Site risk level	Forest stand condition	Possible impact on financial performance	Recommended management response
Low	No damage or only minor damage is observed; transport accessibility is stable.	Planned assortment structure and predictable harvesting costs are maintained.	Harvesting according to the standard production schedule.
Moderate	Local damage, signs of stand weakening, or seasonal access restrictions are present.	Possible reduction in commercial yield and higher costs for specific operations.	Additional inspection, adjustment of harvesting timing, and enhanced sorting.
High	Significant damage, deterioration of sanitary condition, and risk of rapid timber quality loss are observed.	Lower selling prices, increased waste, and need for accelerated removal.	Priority harvesting, separate logistics scenario, and shortened processing time.
Critical	Mass damage, fire impact, severe pest infestation, or sharp deterioration of accessibility is present.	Substantial loss of timber commercial value and risk of unprofitable operations.	Crisis response scenario, selective harvesting of economically usable timber, and reassessment of harvesting feasibility.

Thus, the methodology for monitoring, risk assessment, and forecasting of forest stand conditions should be regarded as an economic management tool for logging enterprises. It helps identify sites where delays may reduce timber quality and cause financial losses, as well as sites where harvesting can be postponed without significant loss of commercial value. In this sense, enterprise sustainability depends not only on technical capacity and available cutting areas, but also on the quality, speed, and practical use of management information.

Rational and economic management of timber resources in the model of a sustainable enterprise

At the final stage of forming a sustainable model of a logging enterprise, the results of monitoring, risk assessment, and forecasting of forest stand conditions should be transformed into specific production and financial decisions. Modern management logic assumes that each forest site is assessed not only by the physical volume of timber, but also by its quality, the possible timing of commercial value loss, harvesting costs, transport accessibility, and potential utilization channels. In this case, timber is treated as an economic asset whose value changes over time and depends on the timeliness of management decisions. The main elements of this model are presented in (table 4).

The proposed model shows that sustainability is achieved not only through cost reduction, but also through precise allocation of timber by utilization channel. High-quality wood should be directed to higher value-added uses, while damaged or low-grade timber requires separate harvesting, removal, and processing scenarios. This enables a shift from reactive responses to a preventive model linking raw material quality, degradation risk, technological decisions, and financial performance.

Table 4. *Elements of rational and economic management of timber resources in the model of a sustainable enterprise (Medvedev & Nazarova, 2025; Medvedev et al., 2024)*

Management element	Content of the management action	Economic significance for the enterprise
Assessment of timber quality	Determination of assortment structure, degree of damage, and suitability of timber for different processing options.	Increases commercial yield and directs raw materials to the most profitable utilization channels.
Prioritization of forest sites	Selection of harvesting sequence considering timber degradation risk, transport accessibility, and expected margin.	Reduces the risk of timber value loss and improves the justification of production planning.
Sorting and allocation of raw materials	Separation of timber by quality, purpose, and economic feasibility of use.	Prevents mixing of high-quality and low-grade timber, reduces waste, and increases overall margins.
Management of damaged and degrading timber	Development of separate scenarios for harvesting, accelerated removal, and processing of damaged raw materials.	Preserves part of the timber resource in commercial circulation and reduces forced losses.
Logistics optimization	Selection of routes, removal timing, seasonal work regimes, and machinery deployment schemes.	Reduces transport costs and increases the profitability of remote or problematic sites.
Financial assessment of decisions	Calculation of expected cost, revenue, margin, and loss risk for each scenario.	Links production decisions with financial performance and long-term enterprise sustainability.

Conclusion

The economic sustainability of a logging enterprise is formed not only through cost control and the maintenance of harvesting volumes, but also through the ability to manage timber quality at all stages of its economic use. Rational allocation of raw materials by processing channel, timely harvesting of degrading sites, reduction of production losses, and the use of monitoring data help preserve the commercial value of timber and improve the predictability of financial performance. Therefore, sustainable enterprise operation under current industry conditions requires a shift from a volume-oriented production logic to an integrated management model in which forest stand conditions, resource risks, technological decisions, and economic efficiency are considered as interrelated elements of a unified system of rational forest use.

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Section 2. Chemisrty

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STUDY OF IR, TGA/DTA, AND ELECTROCHEMICAL PROPERTIES OF A NEW GENERATION ANTIFRIZE CORROSION INHIBITOR

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Abstract

Corrosion is currently a global problem of a worldwide scale. Combating it with corrosion inhibitors (CIs) is highly effective. At present, two million tons of CIs are produced annually across the globe. Corrosion inhibitors are used almost ubiquitously to protect metals. The internal combustion engines of automobiles are also protected from corrosion by CIs added to antifreeze. However, antifreezes are considered very toxic to the environment and human health. This presents a major problem in our era, as the number of cars increases daily and used antifreeze is discharged into the environment. The production of antifreezes that are non-toxic to the environment and human health is one of the most pressing challenges of our time. Naturally, this, in turn, creates the need to discover CIs that are harmless to the environment and human health. We have tested the inhibiting properties of a synthesized CI in our antifreeze, which is based on propylene glycol. To address these issues, the inhibitory properties of potassium adipate (the potassium salt of adipic acid) were studied using electrochemical methods. This was investigated for its use as a non-toxic corrosion inhibitor in a propylene glycol-based antifreeze, which itself is harmless to the environment and human health.

Keywords: *Corrosion inhibitor, antifreeze, propylene glycol, TGA, DTA, IR spectrum; IQ Tracer-100 by SHIMADZU CORP, thermal analyzer SHIMADZU DTG-60*

Introduction

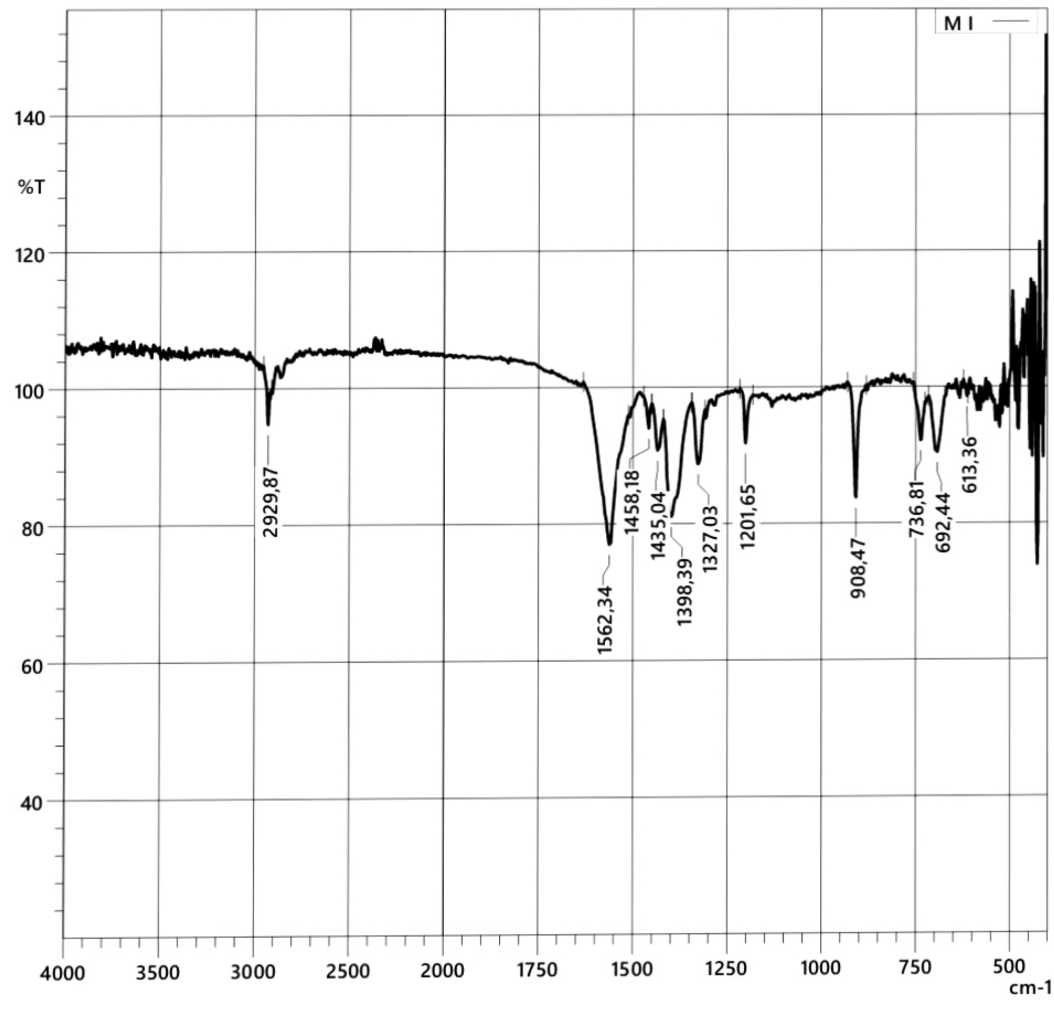
Corrosion is the degradation of metals due to environmental exposure. All nations incur significant economic losses as a result of corrosion (Revie, R. W., & Uhlig, H.H., 2025; Harsimran, S., Santosh, K., & Rakesh, K., 2021; Srikanth, P. S., 2026). While corrosion cannot be stopped completely, it can be slowed down. Substances that slow down corrosion are called inhibitors. The use of corrosion inhibitors (CIs) is one of the most common methods of corrosion control (Oliveira, K. W. D., Faccioli, Y. E. D. S., De Araújo, G. P., Converti, A., Da Silva, R. D. C. F. S., & Sarubbo, L. A., 2026; Al-Amiery, A. A., Isahak, W. N. R. W., & Al-Azzawi, W. K., 2023). One area where CIs are applied is in antifreezes, which are coolants for the cooling systems of automotive internal combustion engines. Initially, phosphates and silicates were used as corrosion inhibitors in antifreezes (Al-Amiery, A.A., Yousif, E., Isahak, W.N.R.W., & Al-Azzawi, W.K., 2023; Coelho, L.B., Lukaczynska-Anderson, M., Clerick, S., Buytaert, G., Lievens, S., & Terryn, H.A., 2022; Ma, I. W., Ammar, S., Kumar, S.S., Ramesh, K., & Ramesh, S., 2022; Alamiery, A., 2025). However, these substances have a toxic effect on the environment. Consequently, there is now a growing interest in carboxylates and "green" plant-based inhibitors, which are harmless to the environment and human health (Huang, L., Chen, W.Q., Wang, S.S., Zhao, Q., Li, H.J., & Wu, Y.C., 2022; Holla, B.R., Mahesh, R., Manjunath, H.R., & Anjanapura, V.R., 2024). The production cost of "green" corrosion inhibitors derived from plants is very high. Therefore, inhibitors based on environmentally safe carboxylates remain the optimal choice. The antifreezes currently in use are manufactured from ethylene glycol (Hans, J.M.J., 2025; Bhattarai, B.C., Parajuli, A., & Stiansen-Snoerud, K.B., 2025). However, ethylene glycol is extremely toxic to both the environment and human health. The use of propylene glycol instead of ethylene glycol solves this problem, as propylene glycol is non-toxic and even used in the food industry. Its price is also not prohibitively high.

Thus, a corrosion inhibitor was synthesized based on such a carboxylate, which is harmless to the environment and human health, and its inhibitory properties were studied.

Materials and methods

Potassium hydroxide (KOH) and adipic acid ($HOOC\text{-}(CH_2)_4\text{-}COOH$) were used for the synthesis of the corrosion inhibitor.

Figure 1. *IR spectrum of the synthesized corrosion inhibitor*



A 10 g sample of potassium hydroxide was weighed and placed into a 250 ml laboratory beaker. The beaker was placed on a magnetic stirrer, and a 5 cm magnetic stir bar was placed inside it. Then, 50 g of distilled water was added, and the stirrer was turned on to the second speed setting. The KOH dissolved quickly in the distilled water. Next, a 13.035 g sample of adipic acid was added. To ensure the reaction went to completion, the solution was stirred on the magnetic stirrer at room temperature for 30 minutes. A pH meter was used to confirm the completion of the reaction: pH=7. That is, in an acidic medium, pH < 7, and in an alkaline medium, pH > 7. A pH meter was used to confirm the completion of the reaction: pH=7.

$$HOOC\text{-}(CH_2)_4\text{-}COOH + 2KOH \rightarrow$$
$$\rightarrow KOOC\text{-} (CH_2)_4\text{-}COOK + 2H_2O$$

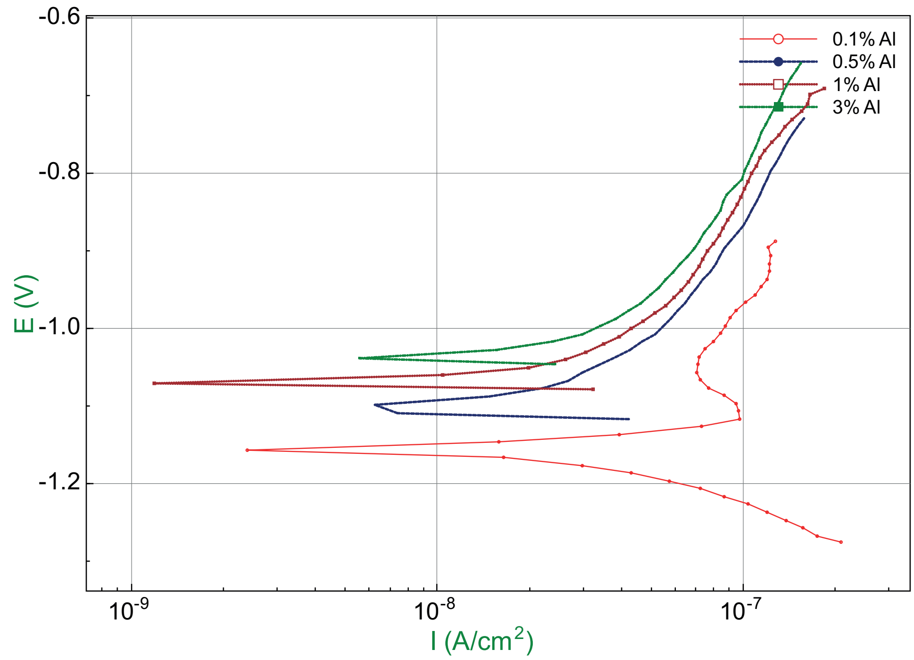
The resulting potassium adipate was then dried in a drying oven for 48 hours. To confirm that a potassium salt of adipine acid was indeed formed in the reaction, the IR spectrum of the dried substance was taken. Using the IR spectrum, it can be determined that the potassium salt of adipine acid has formed completely and that no excess adipine acid remains in the solution.

Infrared spectroscopy was performed using an IQ Tracer-100 spectrometer (SHIMADZU CORP., Japan, 2017). This equipment has a high sensitivity (signal-to-noise ratio of 60,000:1), which allows for the precise analysis of various wavenumbers in the samples despite the low intensity of the spectral lines. The measurement range covers the interval from 4000 to 450 cm^{-1}.

Analysis of the IR spectrum of the synthesized corrosion inhibitor shows that the absorption band at 3650–3500 cm^{-1}, corresponding to the stretching vibrations of the O-H group (not involved in hydrogen bonding), is not observed. This indicates that the adipic acid and potassium hydroxide have completely reacted. Furthermore, the vibration in the 2929 cm^{-1} absorption region indicates the presence of a CH_2 group in the potassium adipate.

The inhibitory properties of the potassium salt of synthesized adipic acid (KI) were studied using a CS-350 potentiostat. For this purpose, four metal samples were prepared for the experiment: steel-3, aluminum, copper, and POS-60 solder. These metals were selected because they are used to manufacture cooling systems for automotive internal combustion engines. The metal samples were first insulated, leaving an exposed surface area of 1 cm^2. The metal surface was thoroughly cleaned with sandpaper and degreased in ethyl alcohol. The samples were then dried at room temperature without a prolonged waiting period.

Figure 2. *Tafel polarization curves for aluminum in antifreeze with a corrosion inhibitor additive*

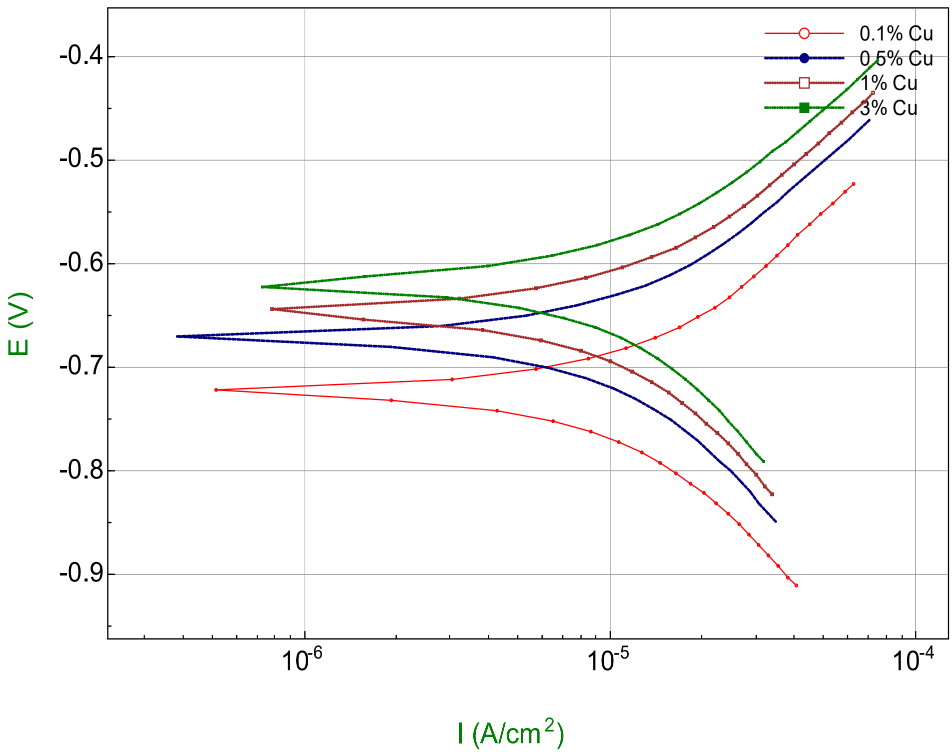


The antifreeze composition was prepared using a propylene glycol base, which, in accordance with modern requirements, is harmless to the environment and human health. To do this, a mixture consisting of 60 grams of propylene glycol and 40 grams of distilled water was prepared, which corresponds to a freezing point of –45 to –60 °C (Hans, J.M.J., 2025). The antifreeze was then precisely measured and poured into a special potentiostat cell, after which KI of the required concentration was added.

A metal sample was connected to the working electrode (WE) of the potentiostat, an Ag/AgCl electrode was used as the reference electrode (RE), and a platinum electrode was connected to the auxiliary electrode (CE). The experiment was conducted with the following parameters: Initial potential: 250 mV below the open-circuit potential (OCP); Final potential: 250 mV above OCP; Quiet time: 1800 s; Scan rate: 1 mV/s. A corrosion test was then conducted, and the inhibitory effect of KI on the four different metals at various concentrations was investigated. The test results are presented in Table 1. The Tafel and LPR analysis plots are provided below.

According to the results in Table 1, the effectiveness of the corrosion inhibitor was evaluated for Steel-3, aluminum, copper, and Solder-60 at various concentrations using the Tafel polarization method.

Figure 3. *Tafel polarization curves in antifreeze with a copper corrosion inhibitor additive*



An analysis of the resulting electrochemical parameters (ba, bc, E0, i0, and corrosion rate) showed that the corrosion protection efficiency reaches its highest value at an inhibitor concentration of 1%. At this concentration, the corrosion current density (i0) is reduced to a minimum, which indicates a significant deceleration of both the anodic and cathodic reactions. Furthermore, the sharp decrease in the corrosion rate (mm/year) points to the formation of a protective adsorption layer on the metal surface. The relative positive shift of the corrosion potential (E0) suggests that the inhibitor has anode-suppressing properties. The analysis indicates that optimal adsorption of the inhibitor molecules on the metal surface and maximum formation of the protective layer occur at a concentration of 1%. Therefore, this concentration can be considered optimal for corrosion protection. The requirements specified in GOST 9.202–2025 are listed in Table 2. Consequently, the corrosion inhibitor we have identified meets the requirements of this GOST standard.

Figure 4. *Tafel polarization curves for Steel-3 in antifreeze with the addition of a corrosion inhibitor*

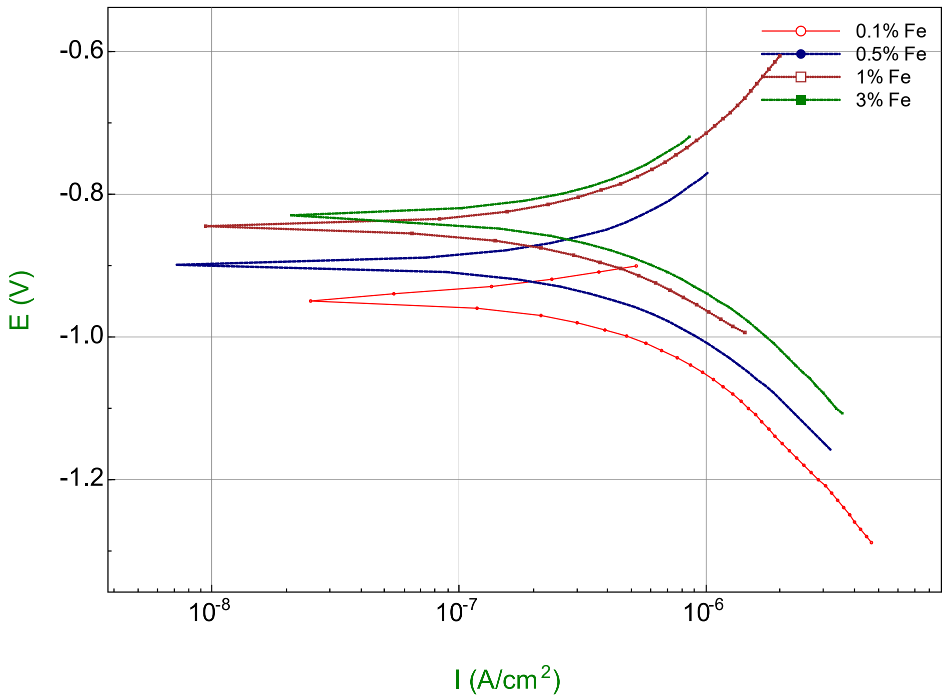
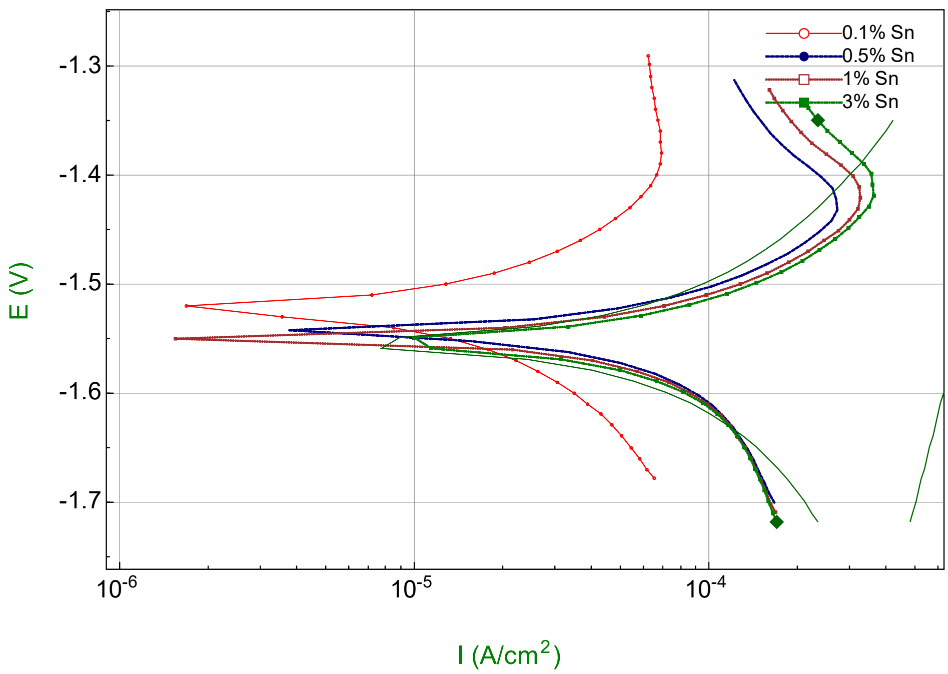


Figure 5. *Tafel polarization curves for antifreeze with the addition of solder-60 corrosion inhibitor*



Results analysis

The thermal properties of the corrosion inhibitor were investigated using a SHIMADZU DTG-60 thermal analyzer, an instrument designed for simultaneous thermogravimetric (TGA) and differential thermal analysis (DTA). During the study of the corrosion inhibitor's thermal characteristics, TGA and DTA were performed concurrently over a temperature range of 29.28–601.68 °C (Fig. 6).

Table 1. *Corrosion test results obtained using a CS-350 apparatus*

Me	IK%	ba (mV/dec)	bc (mV/dec)	i_0 (Amps/cm²)	E_0 (Volts)	Corrosion rate(mm/a)
Al	0.1	1147.5	350.74	1.4393E-07	–1.156	0.0015678
Al	0.5	190.31	82.655	1.1667E-08	–1.1089	0.000127
Al	1	154.45	85	8.0768E-09	8.0768E-09	0.000088
Al	3	183.19	75.735	1.1546E-08	–1.0473	0.0001257
Cu	0.1	841.2	346.6	6.9476E-05	–0.72479	0.081635
Cu	0.5	644.95	328.8	5.0078E-05	–0.67288	0.058842
Cu	1	657.34	373.4	5.5042E-05	–0.64804	0.034675
Cu	3	573.11	477.4	4.5194E-05	–0.61949	0.053103
Fe	0.1	470.64	486.25	9.2606E-07	–0.94724	0.011298
Fe	0.5	548.54	418.1	8.365E-07	–0.89887	0.010206
Fe	1	432.7	351.93	6.245E-07	–0.84685	0.0076192
Fe	3	773.68	475.4	1.0579E-06	–0.83215	0.012907
Sn	0.1	348.38	254.3	1.256E-07	–0.89852	0.047
Sn	0.5	232.54	245.32	5.325E-07	–0.88258	0.045
Sn	1	573.73	541.2	2.253E-06	–0.87225	0.037
Sn	3	448.4	325.1	4.546E-07	–0.89758	0.064

Table 2. *Requirements for the corrosion resistance of metals in accordance with GOST 9.202–2025*

Corrosion rate, mm/year	State
< 0.01	Excellent protection
0.01–0.05	Good / Safe
0.05–0.1	Satisfactory
0.1–0.5	Increased corrosion
< 0.5	dangerous

All samples of the carboxylate inhibitor were thermally analyzed in dynamic mode under an inert argon (Ar) atmosphere. Argon was supplied continuously at a flow rate of 80 ml/min. The samples were heated at a rate of 10 °C/min in an aluminum crucible on a corundum (Al_2O_3) substrate.

Furthermore, the DTA results were used to identify and confirm the endothermic and exothermic effects of the corrosion inhibitor, which allowed for an assessment of its thermal behavior and stability upon heating.

TGA results showed that the carboxylate-based corrosion inhibitor possesses high thermal stability up to 200 °C. In the temperature range of 246–511 °C, a 30.18% mass loss was observed, which is associated with the thermal decomposition of the main organic skeleton. On the DTA curve at 518.56 °C, a strong exothermic effect was recorded, confirming the occurrence of oxidation and molecular destruction processes at this stage. The results obtained indicate that the inhibitor is fully stable in low-temperature antifreeze systems and resistant to high temperatures.

Figure 6. *DTA and TGA analyses of the corrosion inhibitor*

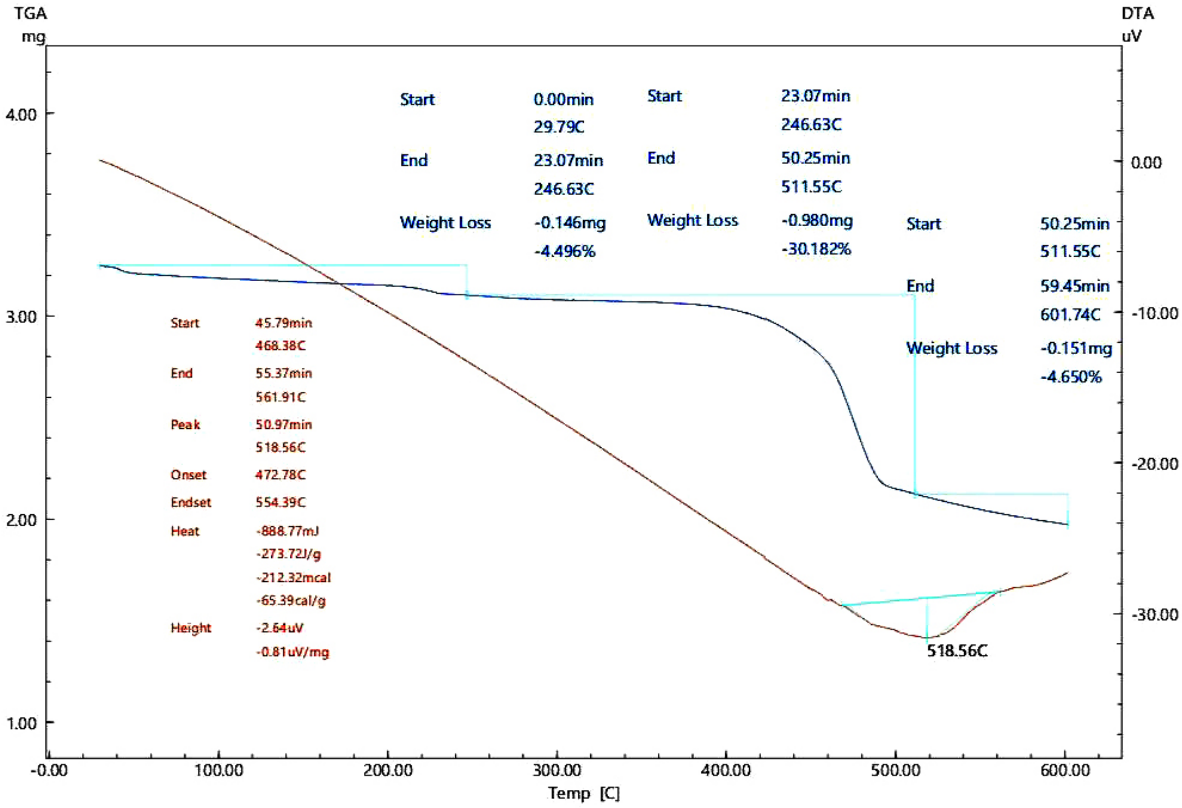


Table 3. *DTA and TGA results*

Temperature (°C)	TGA	DTA	Notes
30–246	Mass loss 4,5%	Weak signal	Moisture release
246–511	A great loss 30%	The peak is high	Basic decomposition
511–601	Additional losses 4,6%	Weak peak	Final oxidation

Conclusion

Based on the study of scientific literature on corrosion inhibitors, the goal was set to investigate the inhibitory properties of adipine acid potassium salt under laboratory conditions. The potassium salt of adipine acid was synthesized in the laboratory. IR, DTA, and TGA spectra were obtained for the synthesized substance. A new generation of antifreeze has been developed that is harmless to the environment and human health. The inhibitory properties of adipine acid potassium salt in an antifreeze medium were studied using a potentiostat. In conclusion, it can be noted that the studied potassium salt of adipine acid can be used as a corrosion inhibitor in new-generation antifreezes.

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DOMAIN-DRIVEN DESIGN AS A BASIS FOR ALIGNING BUSINESS REQUIREMENTS AND IT PRODUCT ARCHITECTURE

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Abstract

The article examines domain-driven design as a methodological basis for aligning business requirements, analytical descriptions of processes, and IT product architecture. The problem of the gap between business logic and technical implementation is revealed, arising from the ambiguity of requirements, insufficient formalization of business rules, and weak connection between analytical artifacts and architectural decisions. It is shown that the domain model functions as an intermediate semantic structure that makes it possible to identify bounded contexts, localize component responsibility, clarify service boundaries, and reduce the risk of technical debt accumulation. It is substantiated that the application of such a model improves the modularity, maintainability, and resilience of the architecture of complex digital systems under changing functional, organizational, and technological requirements.

Keywords: *domain-driven design, domain model, IT product, business requirements, software architecture, technical debt*

Introduction

The development of IT products is increasingly associated with the need to simultaneously consider business objectives, user scenarios, regulatory constraints, and technological parameters of the future system. Business stakeholders, as a rule, describe expected outcomes through applied tasks, operational processes, requirements for efficiency, and the quality of user interaction, whereas engineering teams must transform these expectations into architectural decisions, software components, interfaces, and data models. At this stage, there is a risk of semantic and methodological misalignment between the business description of the product and the logic of its technical implementation, which leads to ambiguous interpretation of requirements, more complex project communication, an increase in architectural rework, and reduced resilience of the IT product to subsequent changes.

In this regard, domain-driven design (DDD) can be considered a methodological basis for aligning business logic with the architecture of a software system. Its significance is determined by the fact that the subject area acts not as an external source of separate requirements, but as a structure-forming element of design that defines the semantic boundaries of the product, key entities, interaction rules, constraints, and scenarios of system change. The aim of the article is to analyze the role of DDD as a tool for formalizing the subject area, reducing the ambiguity of business requirements, and ensuring a more stable relationship between the architecture of an IT product and the logic of its practical application.

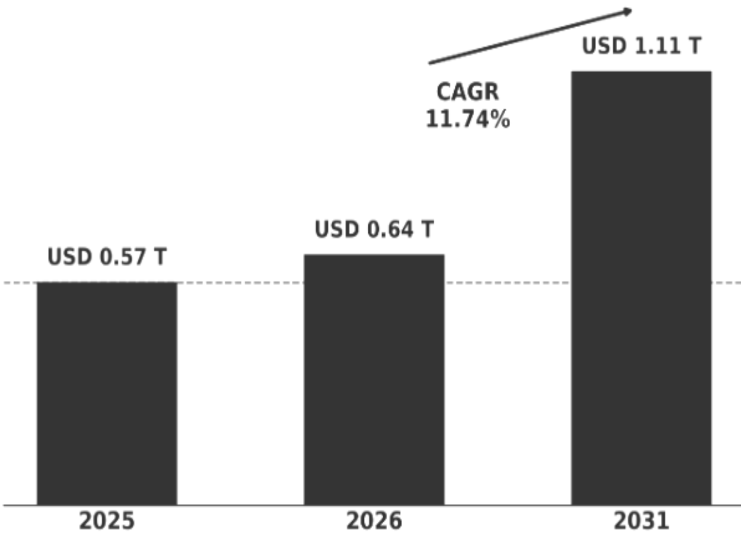
Main part

The problem of the gap between business requirements and IT product architecture

The gap between business requirements and IT product architecture arises when expected business outcomes are not transformed into explicit architectural principles, areas of responsibility, and technical models. Business stakeholders usually describe a product through objectives, processes, user scenarios, and economic effects, whereas engineering teams must translate these expectations into modules, interfaces, data structures, and integration mechanisms (Kovalevskyi, 2026). In the absence of a shared semantic basis, architecture begins to reflect not the logic of the subject area, but a set of separate functional requests.

The relevance of this problem increases as the scale of software product development continues to grow. According to Mordor Intelligence, the global software development market is estimated at approximately $0.64 trillion in 2026 and may reach $1.11 trillion by 2031, with a compound annual growth rate of 11.74% (fig. 1).

Figure 1. *Dynamics of the global software development market size in 2025–2031, trillion dollars (Mordor Intelligence, 2026)*



These data indicate that the alignment between requirements and architecture has direct economic significance. As software development scales, errors in interpreting business logic increasingly affect implementation timelines, maintenance costs, modernization complexity, and the resilience of digital solutions.

One of the main causes of this gap is the ambiguity of requirements. Business formulations often contain implicit rules, exceptions, dependencies, and constraints that are clear to domain experts but insufficiently formalized for engineering implementation. For example, a requirement to automate application processing may include statuses, user roles, data validation procedures, execution deadlines, access rights, and exceptional scenarios. If these elements are not recorded in a shared model, technical implementation is based on assumptions, which increases the risk of duplicated logic and architectural inconsistencies.

Thus, the gap between business requirements and IT product architecture is formed at the intersection of semantic, analytical, and technical factors. Ambiguous requirements, insufficient formalization of business rules, and weak linkage between business descriptions and architectural decisions create conditions under which the system accumulates duplicated logic, excessive dependencies, and contradictory implementation patterns. This substantiates the need for an approach that can use the subject area as a common basis for interpreting requirements and structuring software architecture.

The domain model as a tool for semantic formalization of requirements

Generally, DDD responds to this need by placing the subject area at the center of IT product design. It is based on the formalization of domain concepts, business rules, processes, and bounded contexts, around which software architecture is subsequently constructed. Its main purpose is to ensure consistency between the product's business logic, the analytical description of requirements, and the technical implementation of the software system (Kumar et al., 2025). This consistency is achieved through the domain model, which acts as an intermediate semantic structure between business requirements and architectural decisions.

In this context, the domain model specifies the internal organization of the subject area through entities, processes, rules, roles, constraints, states, and relationships. Unlike isolated functional requirements, it represents product logic as an integrated system of concepts and dependencies, which makes it possible to compare functional descriptions with domain-based modeling principles (table 1).

Table 1. *Comparative characteristics of functional requirements and the domain model in IT product design*

Comparison criterion	Functional requirements	Domain model
Main focus	Define the actions and functions that the system must perform.	Describe the internal logic of the subject area and its structural elements.
Level of representation	User stories, functional scenarios, interface behavior, and expected outputs.	Entities, value objects, business rules, states, relationships, and constraints.
Treatment of business rules	Business rules may remain implicit, fragmented, or distributed across separate requirements.	Business rules are formalized as part of the domain logic and linked to specific entities or processes.
Connection with architecture	Do not always define component boundaries, ownership of logic, or responsibility areas.	Support the identification of bounded contexts, service boundaries, and zones of responsibility.
Risk of ambiguity	Ambiguity may persist due to different interpretations by business and engineering teams.	Ambiguity is reduced through a shared semantic structure and a unified understanding of the subject area.
Practical role in design	Specify what the system is expected to do.	Clarify how business logic should be represented, structured, and preserved in technical implementation.

The comparison presented in Table 1 shows that the domain model performs a broader role than a conventional functional description of requirements. While functional requirements define the expected actions of the system, the domain model establishes the semantic structure within which these actions acquire logical, business, and architectural justification. Therefore, it is necessary to consider not only the differences between these two forms of representation, but also the specific functions performed by the domain model in the formalization of requirements (table 2).

Table 2. *Key functions of the domain model in the semantic formalization of requirements (Nandi & Dey, 2025; D'Anna, 2026)*

Function of the domain model	Content of the function	Significance for IT product design
Semantic structuring	Defines the key concepts, entities, relationships, states, and constraints of the subject area.	Forms a unified understanding of product logic among business, analytical, and engineering teams.
Formalization of business rules	Records rules, exceptions, permissible operations, and transitions between system states.	Reduces the risk of implicit, fragmented, or contradictory interpretation of requirements.
Context delimitation	Separates areas of responsibility through bounded contexts and clarifies the meaning of entities within each context.	Supports more accurate decomposition of modules, services, data models, and architectural boundaries.
Alignment of requirements and architecture	Links business logic with software components, interfaces, APIs, and interaction patterns.	Ensures that architectural decisions are derived from domain logic rather than isolated technical assumptions.
Support for system evolution	Makes it possible to assess how changes in business processes affect entities, rules, contexts, and technical components.	Increases maintainability and adaptability during further product development.

The functions presented in Table 2 show that the domain model acts as a methodological mechanism for translating domain semantics into architectural structure. It defines how business rules, constraints, and contextual meanings should be preserved during implementation and further product evolution.

The relevance of such formalization is confirmed by recent research in product management and business analysis. The ProductPlan State of Product Management 2025 report, based on data from nearly 400 product professionals from different countries, indicates that product strategy is considered one of the most significant responsibilities of product managers, while 59% of teams are focused on consolidating product management tools (ProductPlan, 2025). These data show that modern IT product development increasingly requires a unified management and analytical framework in which strategy, roadmap, prioritization, and requirements are interconnected rather than treated as separate project artifacts.

The importance of the domain model also increases as product development becomes more distributed and cross-functional. According to Atlassian State of Product 2026, which surveyed more than 1,000 product professionals in the United States and Europe, 85% of product teams believe that they influence product strategy; however, 49% report a lack of time for strategic planning and roadmap development, and another 49% indicate insufficient time for data analysis and metric tracking (Crusson, 2025). At the same time, 84% of teams express concern that their current products may not succeed in the market. These findings demonstrate that the growing strategic role of product teams does not eliminate the need for semantic coordination. Under conditions of high organizational workload and limited analytical capacity, teams need a shared model of the subject area that establishes a common language for discussing the product and reduces dependence on fragmented interpretations of requirements.

Architectural effects of DDD

The architectural significance of DDD lies in its ability to align the technical structure of an IT product with the stable semantic boundaries of the subject area. In this approach, modules, services, data models, and interfaces are designed not as isolated technical elements, but as representations of domain entities, rules, and processes. This reduces the risk of dispersing business logic across different system layers and creates a basis for more manageable architectural decomposition (table 3).

Table 3. *Architectural effects of DDD in IT product development (Lytvynov et al., 2026; Özkan et al., 2023)*

Architectural effect	Content of the effect	Significance for an IT product
Decomposition by semantic boundaries	Modules and services are structured according to bounded contexts of the subject area.	Reduces the risk of arbitrary system division based only on technical layers or isolated functions.
Localization of business logic	Business rules, states, constraints, and domain operations are placed within the relevant domain components.	Prevents the dispersion of business logic across the user interface, database layer, and integration services.
Reduction of component coupling	Acceptable dependencies between contexts, services, and data models are explicitly defined.	Improves the controllability of changes and reduces the probability of cascading modifications.
Architectural resilience	Technical decisions are aligned with the long-term logic of domain development.	Allows the product to adapt to new requirements without disrupting previously established architectural decisions.
Limitation of technical debt	Implicit dependencies, duplicated business rules, and uncontrolled growth of logic are reduced.	Decreases the costs of maintenance, modernization, and further system development.
Improved maintainability	Areas of responsibility between components are defined more clearly.	Simplifies change analysis, functional extension, and long-term product support.

Thus, the architectural effects of DDD are manifested not only in increased system modularity, but also in a more accurate alignment of the technical structure of the product with the logic of the subject area. The identification of semantic boundaries, the localization of business rules, and the reduction of component coupling make it possible to view architecture as a manageable system of domain contexts rather than as a set of fragmented technical decisions. As a result, the predictability of changes increases, the risk of technical debt accumulation decreases, and conditions are created for the long-term development of an IT product without disrupting its internal logic.

Applied interpretation of the approach in the design of complex digital systems

The applied significance of DDD is most evident in systems where architecture must simultaneously reflect business goals, operational constraints, scalability requirements, data security, and long-term maintainability. In such conditions, sustainable design cannot be reduced to the choice of a technology stack, database, or integration protocol. The decisive factor is the correspondence between the technical structure and the subject-area logic; otherwise, business rules become duplicated, changes remain local and inconsistent, and the product gradually loses architectural controllability.

In practice, DDD enables a transition from function-centered development to domain-boundary-based design, in which each system component is associated with a specific domain context. This is particularly important when designing digital products that include user management, billing, application processing, analytics, notifications, compliance, and integrations with external platforms. Each of these contexts has its own data model, set of business rules, and correctness criteria. Therefore, domain decomposition makes it possible to more precisely define data ownership, the location of business rules, permissible dependencies between services, and the boundaries of changes that can be implemented locally without affecting the entire system.

The practical significance of correctly identifying domain boundaries is confirmed by the results of an empirical evaluation of DDD in the modular architecture of an information system. In a 2025 study presented in the IEEE ICoCSETI proceedings, the domain-driven approach was analyzed using an academic information system as a case study and assessed through metrics of modularity, coupling, granularity, and stability. The evaluation was aimed not at an abstract description of DDD, but at measuring the extent to which domain decomposition contributes to the formation of a more manageable software system structure (table 4).

Table 4. *Results of modularity evaluation in the application of DDD to an academic information system (Putra et al., 2025)*

Metric	Obtained result	Interpretation for DDD
Service Granularity Metric, SGM	0.18	Indicates the need to assess whether the selected service granularity corresponds to domain boundaries.
Average Lack of Cohesion Metric, ALCOM	0.14	Reflects the degree of insufficient cohesion within the modular structure.
Relational Cohesion, H	0.38; 0.35; 0.21	Shows that internal relationships between types within individual modules require further strengthening.
Number of Operations, NOO	Used to assess the operational density of modules	Helps identify components that are either overloaded with operations or excessively fragmented.
Instability, I	Used to analyze module stability in relation to dependencies	Makes it possible to assess the risk of architectural instability when changes are introduced.

The obtained results show that DDD is most effective when domain decomposition is complemented by quantitative assessment of modularity, granularity, and component cohesion. Its practical value lies not only in identifying domain contexts, but also in verifying whether the proposed service boundaries correspond to the actual structural characteristics of the system. In this sense, the domain model functions not only as a means of describing business logic, but also as an instrument of architectural validation: it makes it possible to compare intended service boundaries with measurable system metrics and to identify areas where component responsibilities should be refined.

The practical relevance of this approach is illustrated by engineering cases from large technology companies. **Uber** describes its platform principle as the use of modular building blocks that allow different business verticals – rides, eats, freight, and autonomous – to operate on a shared infrastructure. In the Unified Checkout case, the company centralized payment orchestration across business lines, which reduced duplication of payment logic and resulted in a 3% increase in conversion, a 4.5% improvement in session recovery, and hundreds of millions of dollars in additional gross bookings (Fiali de Sá, 2024). In another case, related to executive travel, Uber introduced a participant model covering booking, tracking, and billing across more than 30 backend services and 5 client platforms. These examples show that the domain model can serve as a practical mechanism for aligning business scenarios, service boundaries, and reusable architectural components.

A similar principle can be observed in **Square**'s engineering practice, where the Mobile Developer Experience team treated build logic as an independent engineering domain with its own model, responsibility boundaries, and testable rules. During the modernization of the Point of Sale Android repository, the company formalized the build model through convention plugins and separated the build domain from the feature domain. The quantitative results demonstrate the practical effect of this approach: the cyclomatic complexity of the root build script was reduced from 41 to 16, or by 61%, while the complex square_gradle_module.gradle script was reduced from 75 to 0 through removal (Robalik, 2023). At the same time, the repository grew from approximately 3 million to more than 4 million lines of code and from 3,500 to almost 4,400 Gradle modules, while total local build time did not increase significantly. This case shows that domain-oriented thinking is applicable not only to user-facing business logic, but also to internal engineering platforms, where model formalization reduces complexity and improves maintainability.

Conclusion

Thus, DDD makes it possible to consider IT product architecture as the result of the consistent formalization of the subject area rather than as a set of isolated technical decisions. In this context, the domain model performs a coordinating function between business requirements, analytical descriptions of processes, and software implementation. It reduces ambiguity in the interpretation of requirements and increases the consistency of design decisions by linking product logic with architectural structure.

The analysis shows that DDD is especially significant for complex digital systems that evolve under conditions of changing business rules, user scenarios, technological constraints, and increasing requirements for maintainability. The identification of bounded contexts, the formalization of domain entities, and the specification of interaction rules create a basis for a more resilient and modular architecture. Such an architecture can adapt to further changes while preserving the internal logic of the IT product and maintaining alignment between business meaning and technical implementation.

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ATMOSPHERIC WATER GENERATION AS A STRATEGIC RESILIENCE SOLUTION FOR HEALTHCARE SYSTEMS

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Abstract

Healthcare facilities require uninterrupted potable and process water for sterile processing, dialysis and pharmaceutical compounding, yet one in four facilities worldwide operates without reliable on-site supply, and existing atmospheric water generation architectures fail to meet the operational envelope of healthcare deployment because single-pathway condensation systems exceed 0.78 kWh/L below 40% relative humidity and metal-organic-framework sorption systems operate in batch cycles incompatible with continuous draw. A psychrometrically adaptive dual-pathway framework with fleet-level constrained optimization is developed and evaluated against this envelope, coupling vapor-compression refrigeration to a 60:40 silica-gel/zeolite-13X composite sorbent with condenser-to-regenerator heat recovery and a supervisory optimizer phasing regeneration cycle across modules through 200 Hz IEC 61850 GOOSE telemetry. Experimental evaluation on a four-module test array within a Weiss WK11–340/70 climatic chamber across five trial campaigns delivered 0.42 kWh/L specific electrical consumption at the 30 °C and 60% relative humidity design point over 168 hours, 19.6% regeneration electrical demand reduction, 0.21 bar peak manifold pressure deviation under hot-swap substitution at 75% degraded-fleet demand, and 22.8% lifecycle electrical cost reduction at 14.3% capital premium.

Keywords: *atmospheric water generation, healthcare resilience, dual-pathway sorption, fleet-level optimization, psychrometric adaptation, NSF/ANSI conformity, decentralized supply, regeneration heat recovery*

Introduction

One in four healthcare facilities worldwide operates without reliable on-site water service, a figure established by the World Health Organization and UNICEF (2019) global baseline assessment and rising sharply in arid and water-stressed regions where documented municipal supply interruptions exceed 12 hours per month with a frequency that converts the engineering question from one of supply augmentation into one of supply substitution under accreditation constraints. Sterile processing departments, dialysis circuits and pharmaceutical compounding operations cannot be paused for the duration of such interruptions without triggering downstream failures in surgical scheduling, patient safety reporting and pharmacopoeial conformity, and the resulting demand for decentralized substitute supply has positioned atmospheric water generation as a candidate technology whose translation into healthcare-grade infrastructure has been blocked by a single architectural commitment: condensation-only systems exhibit specific electrical consumption above 0.78 kWh/L when inlet relative humidity falls below 40% (Peters et al., 2013), a threshold crossed routinely during the summer months in those same arid geographies where municipal resilience is weakest.

Method

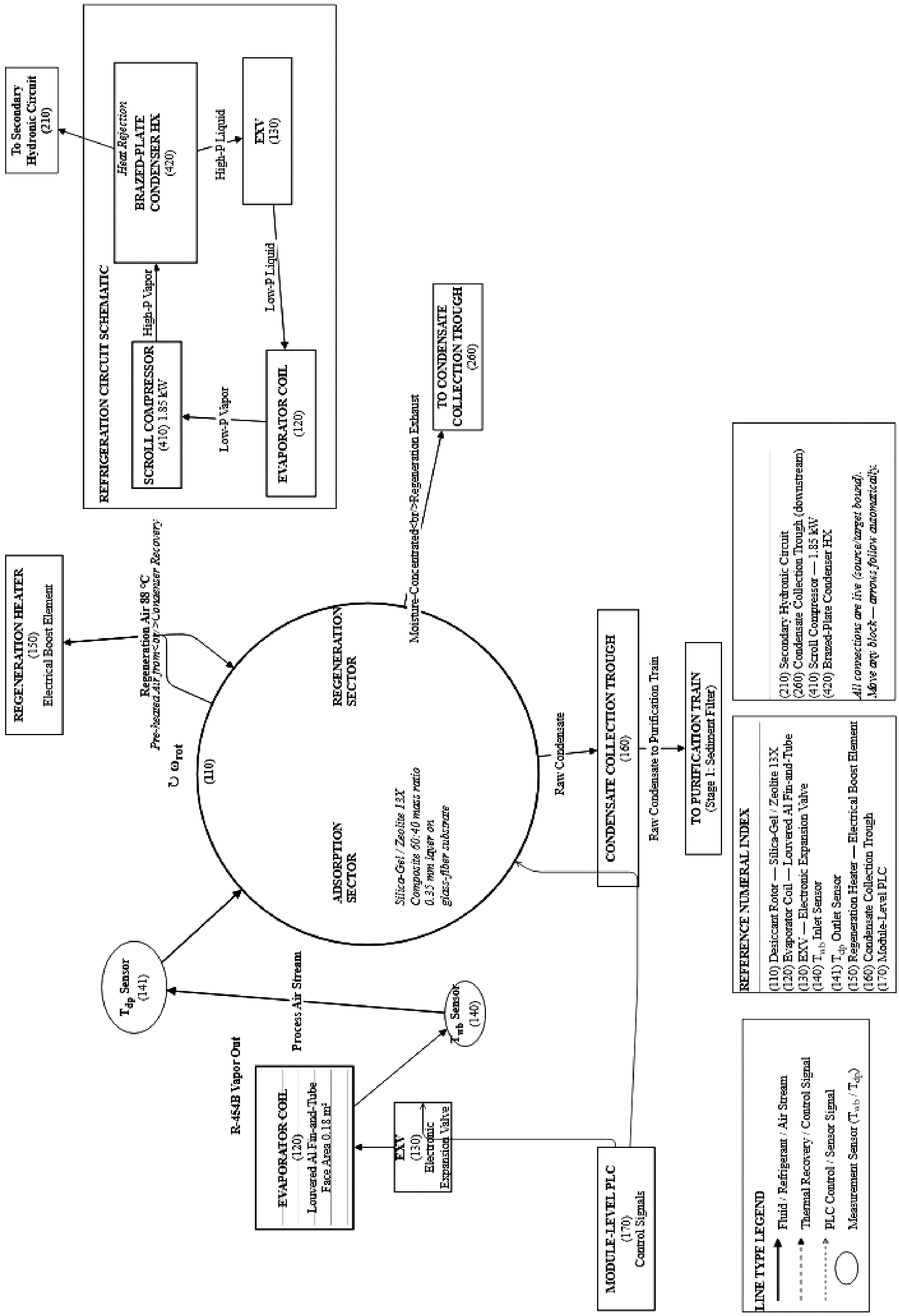
A three-layer coupled model formalizes the proposed architecture. The psychrometric-allocation submodel at the lowest layer reduces the inlet airstream state to a single decision variable <<Eqn001.eps>> and assigns pathway duty through a continuous proportional weighting function w(ΔT) that approaches unity sorption-channel weighting as ΔT exceeds 11 °C, approaches unity condensation-channel weighting as ΔT falls below 5 °C, and blends linearly across the intermediate region, a reduction whose validity rests on the empirical observation across the 352-point commissioning sweep that the ΔT coordinate carries more predictive information for optimal pathway duty than either T_{wb} or T_{dp} considered separately. The module-thermodynamic submodel at the intermediate layer couples a vapor-compression refrigeration cycle on R-454B to a binary silica-gel and zeolite-13X composite sorbent deposited on a corrugated borosilicate substrate at 60:40 mass ratio, with the regeneration airstream preheated through a secondary hydronic loop carrying condenser-rejected thermal energy to the regeneration heat exchanger and reducing the temperature gap that the resistive booster must close from a nominal 88 K to a measured 45.7 K at the design point, with the recovered thermal flux per module reaching 2.1 kW. A constrained quadratic program at the supervisory-optimization layer operates over per-module performance surfaces $P_i(u_i)$ and $W_i(u_i)$, each parameterized as fourth-order polynomial fits to commissioning measurements in the inlet psychrometric coordinates, and minimizes aggregate electrical input subject to the facility demand setpoint W_{demand} and to per-module operational bounds including the 95 °C structural-integrity ceiling on regeneration temperature.

Coupling of pathway weighting and inter-module load distribution as joint state variables, rather than independent design parameters, locates the mechanistic novelty. IEC 61850 GOOSE telemetry transmits the sorbent loading state q_i of each module to the supervisory optimizer at 200 Hz, permitting active avoidance of coincident regeneration phases across modules; the avoided failure mode is simultaneous peaks in resistive heating demand, which under naive phase alignment would draw 12.4 kW peak resistive load across the four-module array and exceed the 9 kW continuous rating of the supply circuit by 38%. Produced water passed a standard sequential conditioning train (UV disinfection, activated carbon, reverse osmosis and calcium-magnesium remineralization) with inline conductivity, pH and turbidity sensors enforcing NSF/ANSI 42, 53 and 58 conformity through module isolation on threshold crossing.

A Weiss WK11–340/70 climatic chamber (11,340 L, ±0.3 K, ±2% RH) served as the test environment, with the four-module array operating against an external manifold instrumented for gauge pressure at 100 Hz. Electrical input was supplied at 400 V three-phase and metered through a class-0.2S power analyzer at 1-second intervals. Each module carried 4.2 kW nameplate cooling capacity, 8.5 L/h production capacity at the design point, and 1.84 kg sorbent loading.

Commissioning surfaces for the supervisory optimizer arose from a factorial sweep across 11 dry-bulb levels between 20 and 35 °C at 1.5 K spacing and 8 relative-humidity levels between 35 and 70% at 5% spacing, yielding 88 points per module and 352 points across the four-module array, each point held for 45 minutes to reach refrigerant and sorbent steady-state, with the polynomial residual maintained

Figure 1. *A schematic diagram of the hybrid condensation-sorption extraction assembly and refrigerant circuit*



below 3% root-mean-square error across the grid. Five trial campaigns followed: continuous 168-hour operation at the design point (three repetitions); envelope-traversal across 20–35 °C and 35–70% at 1 K and 5% grid, each point held 90 minutes (two repetitions); hot-swap substitution at 50%, 75% and 85% degraded-fleet demand (24 events per level); mass-ratio sensitivity across five silica-gel/zeolite-13X cartridges from 80:20 to 40:60 at 1.84 kg total loading, 24 hours per configuration; and production-setpoint sweep at five setpoints from 2.8 to 8.1 L/h, 12 hours per setpoint, with the 60:40 cartridge installed.

Evaluation metrics carried formal definitions: specific electrical consumption <<Eqn002.eps>>, with $V_{certified}$ denoting cumulative volume passing the inline quality array within NSF/ANSI 42 thresholds; per-module volumetric production rate <<Eqn003.eps>> from gravimetric collection; regeneration electrical demand reduction <<Eqn004.eps>> through paired-configuration measurement with the secondary hydronic loop valved out for the baseline; distribution-manifold pressure transient amplitude <<Eqn005.eps>> over the substitution window; quality conformity Q as fraction of cumulative production volume satisfying all three NSF/ANSI thresholds continuously. The lifecycle electrical cost model assumed 0.18 USD/kWh, 4,200 annual equivalent full-load hours derived from the envelope-traversal duty cycle, 0.95 availability factor, 15-year horizon, linear bill-of-materials scaling in module count and no economy of scale on the supervisory-optimizer hardware.

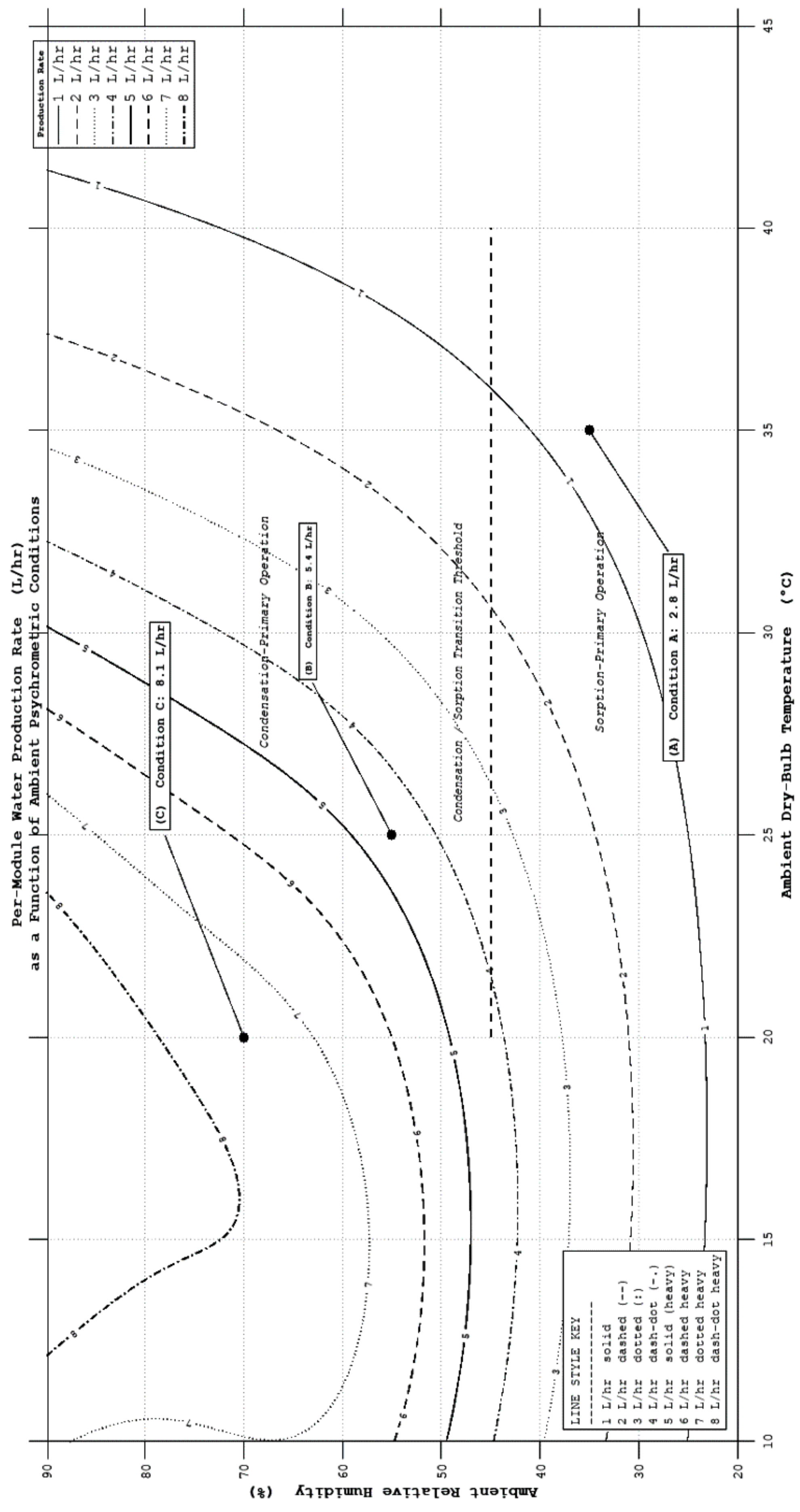
Results

At the 30 °C and 60% relative humidity design point under 70% fleet load corresponding to 22.4 L/h aggregate output across the 168-hour continuous trial, specific electrical consumption registered 0.42 kWh/L and rose monotonically across the envelope-traversal to 0.61 kWh/L at the 35 °C and 35% relative humidity lower-humidity boundary, with the full envelope yielding values between 0.32 and 0.65 kWh/L across the full envelope (Figure 2); the ΔT-governed weighting shifted duty toward the composite sorption channel as ΔT exceeded 5 °C and substituted sensible-cooling work with sorption-regeneration work powered partly by recuperated condenser heat, a substitution whose marginal energy cost favoured the sorption channel by 0.19 kWh/L at ΔT = 9 °C. Beyond the stated envelope, inlet relative humidity below 28% drove specific consumption to 0.94 kWh/L because sorbent equilibrium uptake at $p/p_0 < 0.20$ fell below 0.14 $g_{water}/g_{sorbent}$ and regeneration enthalpy exceeded recuperation capacity, forcing supplementary resistive heating. Under matched chamber conditions and matched 168-hour duration, the proposed method outperformed the Peters et al. (2013) condensation baseline midpoint by 38.2% and the upper bound by 46.2%; the lower-bound comparison (17.6%) rests on unrecoverable manufacturer-declared psychrometric conditions and is reported for completeness.

Regeneration electrical demand reduction measured at 28 °C dry-bulb and 55% relative humidity with regeneration airflow at 0.34 kg/s per module reached 19.6% through the paired-configuration protocol, with envelope-traversal values between 17.8 and 22.1%, arising from the secondary hydronic loop's transport of 2.1 kW condenser-rejected thermal power per module into the regeneration heat exchanger and preheating of the regeneration airstream to 42.3 °C. Saturation of the mechanism and collapse of the reduction below the 15% falsifiability threshold occurred when ambient temperature exceeded 33 °C in combination with simulated condenser-side fouling above 0.18 m²·K/kW, conditions under which the temperature differential driving the secondary loop fell below 12 K.

Hot-swap substitution at 75% three-module aggregate fleet demand corresponding to 16.8 L/h produced peak manifold pressure deviation of 0.21 bar from the 3.2 bar nominal setpoint across the 47-second substitution window measured over 24 events, with the supervisory optimizer redistributing the substituted module's production setpoint across the remaining three modules within a 1.4-second reallocation interval and the 18 L accumulator absorbing the residual flow transient. A counter-intuitive degradation appeared when fleet demand exceeded 85% of remaining-fleet capacity: peak pressure

Figure 2. *A psychrometric contour map of per-module water production rate as a function of ambient temperature and relative humidity*



deviation jumped to 0.58 bar (not a linear extrapolation from the 0.21 bar measurement) because the reallocation interval lengthened to 3.8 seconds once any remaining module operated above 92% of its individual nameplate, exceeded the 0.40 bar tolerance window of the inline quality-monitoring sensor array and triggered a 12.3-second production interruption that defined the operational ceiling of the N+1 architecture.

The mass-ratio sensitivity campaign generated specific electrical consumption values of 0.49, 0.44, 0.42, 0.45 and 0.51 kWh/L at 80:20, 70:30, 60:40, 50:50 and 40:60 silica-gel/zeolite-13X compositions respectively under 22.4 L/h aggregate fleet output, identifying 60:40 as the empirical minimum. The production-setpoint sweep with the 60:40 cartridge at 2.8, 4.5, 6.0, 7.2 and 8.1 L/h returned 0.38, 0.41, 0.42, 0.49 and 0.57 kWh/L respectively, locating the minimum at 71% of the 8.5 L/h per-module nameplate capacity; sizing the array for sustained demand at 70% of aggregate nameplate increased capital cost per design-point litre by 14.3% against a nameplate-sized reference fleet and reduced lifecycle electrical operating cost by 22.8% over the 15-year horizon at 0.18 USD/kWh.

Limit-case collapse manifested at 38 °C and relative humidity below 22%, outside the operational envelope of the falsifiable contribution, where specific electrical consumption rose to 1.31 kWh/L and per-module production rate fell to 1.6 L/h through a double mechanism: the dewpoint fell below 12 °C and forced evaporator surface temperatures into the frost-formation regime, and the sorbent relative pressure dropped below 0.18 with equilibrium uptake at 0.11 $g_{water}/g_{sorbent}$. Deployment in climatic zones with more than 90 annual days of daytime relative humidity below 22% therefore voids the design claims.

Discussion

Re-evaluating the 38.2% reduction in specific electrical consumption against Peters et al. (2013) at the upper bound of the cited range (0.78 kWh/L) yields 46.2% and stays within a like-for-like envelope; at the lower bound (0.51 kWh/L) the reduction shrinks to 17.6% and the manufacturer-declared psychrometric conditions become unrecoverable from the original publication, rendering the lower-bound comparison uninterpretable. The mechanism explaining the residual advantage is specific: the condensation-only machines lose approximately 0.27 kWh/L to the latent-cooling burden imposed by continued vapor-compression operation below 50% relative humidity, and the framework reported here reassigns that burden to the sorption pathway through the ΔT-governed weighting function before it materializes as compressor electrical demand. The condensation-centred literature downstream of Wahlgren (2001), extended through thermoelectric refinement by Eslami et al. (2018), has treated this latent burden as a coil-and-refrigerant problem and accumulated gains in the low single percentages per generation; the dual-pathway result reported here is a refusal to participate in that design problem, and the magnitude of the result is therefore not directly comparable to the incremental literature it appears to outperform.

The duty-factor ceiling that Tu et al. (2018) located within the fixed-architecture sorbent system, and that they concluded could not be eliminated within a single device, dissolves at the fleet level once sorbent loading state q_i is exposed to a supervisory optimizer that phases regeneration cycles across modules; Tu et al. (2018) analyzed the duty-factor problem at the single-device boundary where regeneration interrupts production by construction, and the framework reported here treats the array as the production unit and the individual module as a phase-shifted contributor, such that the array-level production curve remains continuous despite per-module regeneration discontinuity. The 1.4-second reallocation interval at 75% fleet demand demonstrates that phase-shifting operates within timescales compatible with continuous-draw infrastructure, and the 17.8–22.1% regeneration electrical demand reduction across the envelope demonstrates that recovered condenser heat closes the energy gap that would otherwise penalize the phase-shifting strategy. A tension that the data make visible and that the framework does not eliminate concerns the statistical independence assumption underlying phase shifting: the supervisory optimizer treats sorbent loading states q_i as approximately independent across modules, an assumption verified across the 240 cycles accumulated in the 168-hour and envelope-traversal trials but unverified across the 22,000-cycle horizon corresponding to a 15-year service life, and any correlated drift in sorbent kinetics across modules sharing a common borosilicate substrate batch would degrade independence and erode the fleet-level efficiency advantage by a magnitude that the present trials cannot bound. The 0.21 bar peak manifold deviation under hot-swap at 75% degraded-fleet demand provides a continuity benchmark against which future MOF-based system-level integrations can be evaluated quantitatively; the batch-cycle architectures characterized by Kim et al. (2017) and Hanikel et al. (2020) deliver uncontested volumetric yields under low-humidity conditions but have not been operated under manifold-pressure stability requirements or N+1 redundancy with live module substitution.

The minimum specific consumption at 71% of nameplate capacity contradicts the implicit sizing convention reflected in the system-integration literature (Wang et al., 2017; Zhou et al., 2020), which treats nameplate capacity as the appropriate sizing reference for atmospheric water generation infrastructure; the 14.3% capital premium paired with 22.8% lifecycle electrical cost reduction across the 15-year horizon at 0.18 USD/kWh demonstrates that the standard sizing convention has been transferring lifecycle cost from capital to operating budgets, a transfer concealed in component-level analyses and visible only under realistic tariff conditions.

The arid-extreme collapse at 38 °C and below 22% relative humidity confirms the viability boundary identified by Lord et al. (2021), and the framework does not eliminate it; any healthcare facility located in a climatic zone with sustained arid-extreme conditions requires hybridization with a non-atmospheric backup source, a constraint that bounds the architectural envelope.

Sustained 0.42 kWh/L specific consumption over 168 hours with N+1 redundancy and inline NSF/ANSI 42, 53 and 58 conformity crosses the operational threshold at which decentralized atmospheric supply becomes a credible substitute for municipal supply during interruption events, reframing the contribution against the WHO/UNICEF (2019) baseline assessment beyond an efficiency metric. The lifecycle electrical cost calculation remains bounded by an unresolved degradation question: the 240 cycles accumulated across all trials sit two orders of magnitude below the 22,000 cycles of a 15-year service life, and neither Fathieh et al. (2018) nor Shan et al. (2021) characterize the binary silica-gel/zeolite-13X system on a borosilicate substrate directly. Accelerated-cycling trials are a prerequisite for commercial deployment.

Conclusion

Three previously incompatible operational constraints (sub-0.65 kWh/L specific electrical consumption across the 35–70% relative humidity envelope, manifold pressure deviation below 0.21 bar under live module substitution, and uninterrupted NSF/ANSI 42, 53 and 58 conformity over 168 hours) now hold simultaneously within a single architecture, moving atmospheric water generation from the category of supplementary off-grid technology into the category of accreditable healthcare supply during municipal interruption events. The result is bounded geographically by the arid-extreme collapse threshold at 38 °C and below 22% relative humidity, and bounded temporally by the gap between the 240 cycles accumulated in the reported trials and the 22,000 cycles a 15-year service life imposes; facilities in climatic zones that regularly breach the humidity floor require hybridization with a non-atmospheric backup source. The immediate priorities for subsequent work are accelerated-cycling trials on the 60:40 silica-gel/zeolite-13X composite under the 88 °C regeneration setpoint, validation of the phase-shifting independence assumption across correlated sorbent batches, and extension of the psychrometric envelope toward the 15–35% relative humidity range relevant to continental arid and high-altitude deployment contexts.

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AUTOMATION OF CONSTRUCTION RISK MANAGEMENT PROCESSES BASED ON MACHINE LEARNING ALGORITHMS: PROBLEM FORMULATION AND EFFICIENCY ANALYSIS

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Abstract

The article examines theoretical and applied aspects of automating construction risk management processes using machine learning algorithms. It is shown that under conditions of high uncertainty in construction projects, traditional risk management approaches are limited in terms of responsiveness and forecasting accuracy. A conceptual model of risk management automation is considered, taking into account schedule, cost, quality, resource, and contractual factors. The main classes of machine learning algorithms applicable to risk prediction and ranking are analyzed. Based on a comparative analysis of published practical cases from large construction companies, the applied effects of implementing algorithmic solutions are demonstrated, including reduced losses, increased transparency of control, and improved quality of managerial decision-making.

Keywords: *construction risk management, machine learning, automation, construction projects, risk prediction, digitalization of construction, efficiency analysis*

Introduction

Amid the growing complexity of investment and construction projects, rising resource costs, and stricter requirements for deadlines and quality, risk management has become a fundamental condition for project sustainability. The construction industry is characterized by a high level of uncertainty driven by organizational, financial, technological, contractual, logistical, and external economic factors. At the same time, traditional risk management approaches remain largely reactive, as they rely on expert judgment, retrospective analysis, and fragmented information processing, which limits the timely detection of threats and weakens managerial responsiveness. Under conditions of digital transformation, the importance of tools capable of automated data analysis, identifying hidden interdependencies, and forecasting deviations at early stages is increasing.

One of the most promising ways to address this challenge is the use of machine learning (ML) algorithms, which improve the accuracy of risk identification, formalize probability assessment, and expand the analytical capabilities of project management systems. The aim of the study is to formulate the task of automating construction risk management based on ML and to assess its effectiveness in decision-support systems. The scientific novelty lies in substantiating construction risk management automation as an integrated analytical framework combining risk identification, classification, forecasting, and prioritization. The practical significance of the study is associated with improving the validity of managerial decisions and enabling earlier detection of critical deviations in time, cost, and quality.

Methods

The study employs a combination of general scientific and applied research methods, including the analysis and synthesis of academic literature on construction risk management, the digitalization of construction processes, and the use of ML algorithms for forecasting and decision support. The methodological foundation is based on systems and process-oriented approaches, which make it possible to examine risk management as a continuous cycle of identification, assessment, monitoring, and mitigation throughout the implementation of a construction project. To formalize the problem setting, structural and functional analysis, risk classification, and comparison of ML algorithms with typical construction risk management tasks were applied. The effectiveness of automation was examined through a comparative analysis of published studies and practical cases describing algorithm-based approaches in construction risk management, with attention to reported effects related to risk detection, schedule control, rework prevention, and decision-support quality.

Results

To achieve the objective of the study, the theoretical foundations of risk-oriented management in construction were examined, the potential for integrating ML algorithms into risk identification, assessment, and forecasting procedures was analyzed, and practical aspects of evaluating their effectiveness in the context of construction project implementation were presented.

Theoretical and methodological framing of construction risk management automation

In academic and applied discourse, construction risk can be defined as the probability of events and conditions that may cause deviations from project targets in terms of time, cost, quality, safety, and contractual performance (Teymoori S. et al., 2026). In construction, risks arise not within a single local process but at the intersection of design, procurement, construction operations, contractor coordination, regulatory procedures, and the external macroeconomic environment. Therefore, risk management should be viewed not as an occasional expert assessment but as a continuous process of identification, classification, monitoring, and preventive response. The relevance of this approach is reinforced by the scale of the sector itself: according to Deloitte, the global construction market may grow from $11.39 trillion in 2024 to $16.11 trillion by 2030, while smart construction has already moved from an experimental concept to an operational necessity (Deloitte, 2025).

Table 1. *Classification of construction risks for automated analysis (Dikmen I. et al., 2025; Hrebeniuk O., 2026)*

Risk category	Risk group	Typical manifestations	Data for automated analysis
Internal risks	Schedule risks	Delays in project stages. Deviations from the planned timeline. Cascading shifts of subsequent activities.	Project schedules. Actual progress data. Construction logs.
	Cost risks	Budget overruns. Increase in material and labor costs. Unplanned expenses.	Cost estimates. Payment records. Material price data. Labor indicators.

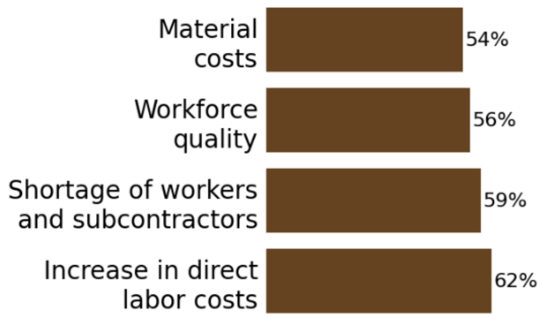
Risk category	Risk group	Typical manifestations	Data for automated analysis
	Resource risks	Shortage of workforce. Lack of equipment or materials. Limited subcontractor capacity.	Workforce data. Supply chain data. Equipment utilization metrics.
	Quality and production risks	Defects in construction works. Rework. Decrease in productivity.	Inspection reports. Quality control data. Production reports.
	Contractual and regulatory risks	Delays in approvals and permits. Payment delays. Contractual disputes.	Contract terms. Permit documentation. Payment discipline data.
External risks	External environment risks	Inflation. Supply chain disruptions. Regulatory changes. Macroeconomic instability.	Market indicators. Logistics data. Regulatory updates.

The multidimensional nature of construction projects requires a structured classification of risks by source and impact. Table 1 presents the main risk groups that form the uncertainty profile of construction projects.

The systemic nature of construction risks is confirmed by recent quantitative evidence. According to Autodesk, a typical construction project involves an average of 42 external stakeholders across its lifecycle, which increases the likelihood of information loss, coordination failures, and cascading errors between project stages. The same source reports that 89% of construction executives experienced payment delays during the previous year (Autodesk, 2025). Under such conditions, static risk registers and periodic reporting are insufficient; effective risk management requires an architecture capable of processing multiple interrelated factors in near real time and detecting early signs of deviation before critical consequences occur.

From a practical perspective, the most significant risks in construction projects remain those related to resource constraints and cost escalation. This is confirmed by the results of the 2025 AGC survey conducted among construction firms and contractors (fig. 1).

Figure 1. *Key challenges faced by construction contractors according to the AGC 2025 survey (AGC, 2025)*



The results of the study emphasize that the task of automating risk management should be focused not only on identifying already occurred deviations, but also on predicting the likelihood of their occurrence under the influence of cost, time, resource, and organizational factors.

In this context, ML algorithms are important as a means of shifting construction risk management from a reactive to a predictive model (Hriday M. S.H. & Rehman A., 2025). Industry evidence shows that the sector is already moving in this direction: according to Deloitte, the share of construction companies in the Asia-Pacific region using artificial intelligence and ML increased from 26% in 2023 to 37%, while the average number of adopted digital technologies rose from 5.3 to 6.2 per company. In the United States, AGC reports that 44% of firms expect to increase investment in artificial intelligence, and the 2026 AGC survey shows its growing use in office applications, cost estimating, design, site monitoring, procurement, and scheduling. This indicates that ML-based risk automation already has a practical foundation and can be integrated into key construction processes.

Accordingly, the conceptual framework for automating construction risk management can be defined as the development of an intelligent system that processes schedule, cost, supply, productivity, quality, contractor, permitting, and external constraint data to generate risk probability estimates, classify events by criticality, and support preventive action. Within such a system, ML algorithms should address three main tasks: identifying hidden relationships among project parameters, predicting adverse events, and ranking risks by managerial priority.

Thus, the theoretical and methodological framing of construction risk management automation shows that ML should be treated not as an auxiliary digital tool, but as a core analytical mechanism for continuous risk identification, prediction, and prioritization. This creates the foundation for developing integrated risk-oriented systems capable of improving the timeliness, accuracy, and managerial value of decision-making in construction projects.

Comparative analysis of ML algorithms for predicting and ranking construction risks

The application of ML algorithms in construction risk management is primarily associated with the transition from descriptive and expert-based approaches to predictive data-driven analysis. In the literature, such algorithms are viewed as tools for identifying nonlinear relationships between project parameters, estimating the probability of adverse events, and supporting the selection of preventive management actions (Oduro S., 2025).

Table 2. *Comparative characteristics of ML algorithms for predicting and ranking construction risks*

Algorithm class	Typical tasks in construction risk management	Advantages	Limitations
Linear and logistic models.	Basic estimation of the probability of schedule and cost deviations. Primary risk classification.	High interpretability. Low data requirements. Ease of implementation.	Limited ability to capture complex nonlinear relationships.
Decision trees and ensemble models (Random Forest, XGBoost, LightGBM, boosting).	Ranking risk factors. Predicting schedule delays, accidents, and cost overruns.	High accuracy. Robustness to mixed features. Ability to assess feature importance.	Risk of overfitting. Need for hyperparameter tuning.
Neural network models and multilayer perceptrons.	Complex multiparameter prediction of quality, schedule, and cost outcomes.	Ability to detect hidden relationships. High performance on large datasets.	Lower transparency. Dependence on the quality of the training data.
Graph neural networks.	Modeling interconnected risks between participants, stages, and project nodes.	Good representation of the network nature of construction projects.	High complexity of implementation and data preparation.
Explainable AI models and SHAP-based analytics.	Interpretation of risk factors. Explanation of predictions for management purposes.	Increased trust in the model. Better applicability in decision-making.	Require an additional analytical layer.

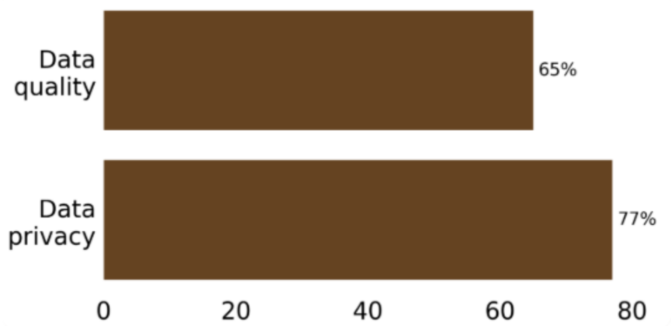
A systematic review of 84 peer-reviewed studies published between 2014 and 2024 identified five major artificial intelligence domains in construction risk management: ML, natural language processing, knowledge-based reasoning, optimization algorithms, and computer vision (Tian K., 2025). Among these, ML serves as the main predictive mechanism for modeling cost, schedule, safety, quality, and supply risks, making algorithm selection a key architectural component of automated risk analysis systems.

Considering the specific features of the management object, ML algorithms in construction risk systems should be selected based on the type of task, the nature of input data, and the requirements for result interpretability (table 2).

Empirical results from recent studies confirm that ensemble and neural network approaches demonstrate high practical potential in construction. For example, a 2025 study based on 1,015 projects and 499 defect categories reported that a multilayer perceptron achieved 94.1% accuracy in quality prediction and 98.4% in schedule status prediction, indicating the strong suitability of such models for early detection of deviations in key project parameters (Fan C. L., 2025).

At the same time, high accuracy alone does not ensure successful implementation. In construction risk management, interpretability, data quality, and integration into managerial processes are critical. The KPMG Q4 AI Pulse Survey (2025) indicates that data quality remains one of the key challenges for corporate AI adoption (fig. 2).

Figure 2. *Major barriers to scaling AI systems according to the KPMG Q4 AI Pulse Survey (KPMG, 2025)*



These findings indicate that in construction, priority should be given not merely to the most accurate models, but to algorithms that balance predictive performance, interpretability, and robustness to heterogeneous and imperfect project data. Therefore, a theoretically grounded system for construction risk automation should rely not on a single universal model, but on a set of coordinated algorithms, selected according to the type of risk, data quality, and the level of managerial decision-making.

Practical assessment of the effectiveness of algorithmic solutions in construction risk management: a comparative case analysis

The practical value of ML-based automation in construction risk management is most evident in real projects, where digital solutions function not as auxiliary analytics but as embedded elements of the operational management system. Corporate practice highlights several stable application areas, including the prediction of schedule deviations, prevention of defects and rework, mitigation of safety risks, automated monitoring of actual site conditions, and support for supply chain management. In the latter case, algorithmic tools help detect potential supply disruptions, anticipate shortages of critical resources, and reduce the transfer of logistics-related risks to project schedule, cost, and production performance (Miloserdov A., 2025).

Notably, despite differences in project profiles and implementation scales, a common pattern can be identified: algorithmic solutions shift risk management from a reactive response to consequences toward the early detection of deviations and timely intervention. Large construction projects, according to recent McKinsey analyses, often experience cost overruns of approximately 80% and schedule delays of around 50%, highlighting the critical importance of proactive risk management.

Practical implementation of algorithmic solutions in construction demonstrates that the greatest effect is achieved when ML methods are integrated into schedule control, defect prevention, and remote verification of actual site conditions. For example, **Suffolk Construction** applied the nPlan platform for AI-based risk management and forecasting in a hospital project in Boston. The case emphasizes the use of algorithmic forecasting for early identification of schedule risk zones and support of managerial decision-making during project execution (nPlan, 2024).

A representative example of artificial intelligence application in construction risk management is the case of **Nibbi Brothers General Contractors**, where AI-driven visual analytics within OpenSpace were used for early detection of discrepancies, prevention of rework, and reduction of coordination and cost-related risks. According to the company, this resulted in savings of $58,000 in travel costs, prevention of $63,000 in losses from a single rework incident, and elimination of $15,400 in billing discrepancies (OpenSpace, 2023). A similar effect was observed at **U. S. Engineering,** where the use of OpenSpace enabled savings of up to 10 hours per week through remote monitoring and earlier detection of deviations. These examples indicate that ML delivers the greatest value in construction when it is embedded not as an isolated analytical tool, but as part of a continuous system for preventing schedule, quality, and coordination risks.

As an additional example of a U.S. construction company applying ML to risk forecasting, the case of **JE Dunn Construction** using the Buildots platform is particularly relevant. In the published case, Buildots is described as being used for forecasting outcomes, data-backed delay mitigation, and improving execution control accuracy; notably, JE Dunn has already deployed the solution across projects totaling more than 3 million square feet. At the platform level, Buildots reports that its AI-powered progress tracking and delay forecasting can reduce delays by up to 50%, which makes this case relevant for analyzing machine-learning tools for schedule-risk prediction in construction (JE Dunn, 2025). At the same time, it should be noted that the publicly available JE Dunn case does not disclose company-specific before-and-after performance metrics, so the quantitative interpretation should be limited to the reported scale of deployment and the technology-level effect claimed by the platform.

Taken together, the reviewed cases show that the practical effect of ML in construction risk management is manifested not only in improved forecasting accuracy, but also in measurable reductions in rework, coordination losses, time expenditure, and schedule-related uncertainty. This suggests that the effectiveness of algorithmic solutions depends primarily on their integration into routine project control processes, where predictive analytics and AI-based monitoring can support earlier and more informed managerial intervention.

Discussion

The analysis shows that the effectiveness of ML in construction risk management depends less on adoption per se and more on how models are embedded into the project management workflow. The reviewed cases indicate that the greatest impact is achieved when algorithmic solutions address specific tasks – such as schedule deviation forecasting, rework prevention, reduction of coordination losses, and early detection of discrepancies between the design model and actual site conditions. At the same time, the results reveal limitations of a universal approach: some solutions are more effective in visual quality control, others in schedule risk prediction, while risks related to team coordination, subcontractor interaction, and supply chains require consideration of organizational dependencies, data exchange discipline, and logistical stability (Naidenova M., 2026). This suggests that ML cannot be treated as a standalone tool capable of uniformly addressing all categories of construction risks.

Equally important is the role of the organization's digital maturity. Fragmented data, lack of standardization, weak integration between project participants, and disconnections between planning, procurement, and site execution significantly reduce the practical value of even highly accurate models. In such conditions, algorithms may detect risks, but without the team's ability to interpret signals and translate them into timely actions in scheduling, procurement, or responsibility allocation, the managerial effect remains limited. Therefore, further development of ML-based risk management in construction should focus not only on improving model performance, but also on building integrated data environments where predictive analytics is embedded into team collaboration, supply chain coordination, and real-time decision-making processes.

Conclusion

Automation of construction risk management based on ML should be approached as the transition from periodic expert judgment to continuous predictive control of the project environment. The study shows that the object of automation is not an isolated risk, but an interconnected set of deviations related to schedule, cost, quality, safety, and contractual performance. For practical implementation, priority should be given to models that can both predict adverse events and rank risk factors by criticality. In this context, ensemble methods, neural network models, and interpretable analytical tools appear to be the most suitable options for construction projects, since they combine predictive capability with managerial usability.

The case analysis indicates that the greatest effect is achieved when algorithmic solutions are embedded into routine project processes rather than used as stand-alone analytical modules. In practice, this means that construction firms should integrate ML into schedule control, quality verification, site monitoring, and procurement coordination, while ensuring consistent project data and clear procedures for acting on model outputs. Thus, the most effective development path is the creation of integrated risk-oriented digital systems that combine prediction, monitoring, and response mechanisms. Further research should focus on industry-specific datasets, comparative validation of models across project types, and the development of implementation criteria linked to organizational scale and digital maturity.

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INFRASTRUCTURE AND ECOSYSTEM FOR THE REGENERATION AND RECIRCULATION OF PROCESS FLUIDS (Modular Architecture of Systems for the Regeneration and Recirculation of Complex Process Fluids, Including Water and Aqueous Solutions)

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Abstract

The article discusses the development of an integrated infrastructure and ecosystem for water treatment, water conditioning, and the regeneration and recirculation of process fluids intended for modern industrial applications. Particular attention is devoted to the creation of a comprehensive modular technology for the treatment of industrial wastewater based on a sequence of autonomous yet technologically coordinated processing stages employing different physical and chemical treatment principles.

The proposed concept is founded on the implementation of complete, standardized, and autonomous technological modules that may be combined into integrated treatment systems depending on the composition, characteristics, and intended reuse of process fluids. Within this framework, each stage of the treatment process performs a specialized technological function while remaining operationally independent, thereby increasing the flexibility, reliability, scalability, and overall efficiency of the system.

The article also examines innovative engineering concepts proposed by *Ostap Victor Vlad*, particularly the hierarchical architecture of specialized technological modules possessing narrow functional specialization, autonomous operating cycles, and the ability to operate without the use of chemical reagents or synthetic activating additives. This modular engineering approach makes it possible to construct higher-level technological systems from lower-level autonomous modules while maintaining maximum technological and economic efficiency.

Special emphasis is placed on reagent-free regeneration technologies that enable the immediate transition from the regeneration process to continuous online recirculation of process fluids. The absence of externally introduced chemical reagents preserves the physicochemical properties of treated liquids, maintains a high level of process-fluid quality, and significantly improves the environmental sustainability and operational efficiency of industrial water treatment systems.

The proposed technological infrastructure, modular architecture, regeneration methods, and process-fluid recirculation technologies are presented as innovative engineering developments with significant practical potential for modern industrial production, environmentally sustainable manufacturing, and advanced water resource management, while also demonstrating substantial prospects for further technological development and intellectual property protection through integrated and combinatorial engineering solutions.

Keywords: *Infrastructure and ecosystem for water treatment and water conditioning; infrastructure and ecosystem for the regeneration and recirculation of process solutions; water and aqueous solutions; integrated technology for the treatment of industrial wastewater based on a sequence of interconnected yet operationally independent processing stages; integrated modular technology implemented through complete, autonomous, and standardized technological modules, in which each stage of water treatment is represented as a sequential processing operation employing distinct physical and chemical treatment principles*

Introduction

At present, various industries that utilize water for technological and manufacturing purposes employ several principal methods for the treatment and purification of water contaminated by industrial products, process by-products, and technological waste streams. The most widely used approaches include the following:

- **Chemical reagent-based water treatment**, encompassing several modifications of this method and its combinations with other treatment technologies. This approach remains the predominant industrial solution, accounting for more than **70%** of the global water treatment technology market;
- **Reagent-free water treatment and purification**, represented by several principal technological modifications that differ in their operational capabilities and performance characteristics. These methods currently account for less than **20%** of the water treatment technology market;
- **Combined treatment technologies**, which generally integrate reagent-based and reagent-free methods together with additional technological processes adapted to specific industrial operating conditions. These technologies currently represent approximately **10%** of the market and continue to demonstrate significant growth potential.

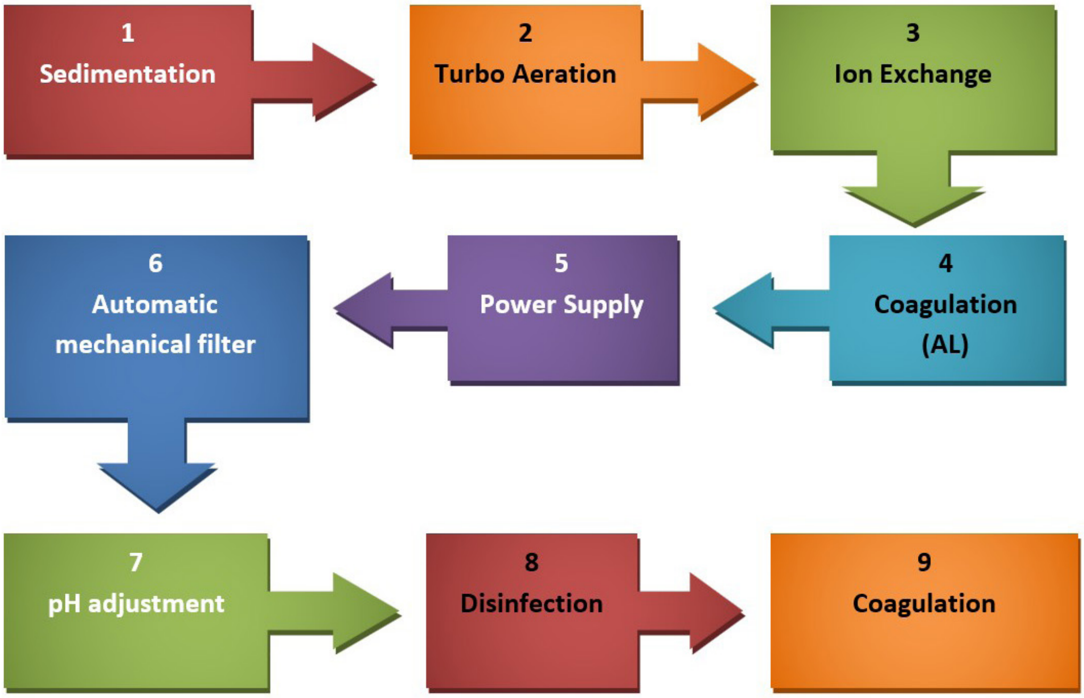
The challenges currently encountered in industrial water treatment and water conditioning can no longer be effectively addressed using conventional technologies alone. Modern industrial production requires comprehensive engineering solutions, as isolated or partial technological improvements fail to satisfy the increasingly stringent environmental, technological, and economic requirements imposed on contemporary manufacturing processes. Consequently, neither individual treatment methods nor existing combinations of conventional technologies are capable of fully meeting the continuously evolving demands of modern industry.

Taking these circumstances into consideration, and building upon recently emerging innovative engineering concepts, the author proposes an integrated technology for the treatment of industrial wastewater based on a sequence of technologically coordinated yet operationally independent processing stages.

More specifically, the complete water treatment process may be considered as a succession of individual treatment operations, each employing a distinct physical or chemical mechanism of action. Every processing stage performs a specialized technological function while contributing to the overall efficiency of the integrated treatment system.

Combining these engineering principles with the latest innovative concepts proposed and published by distinguished technology developer Ostap Victor Vlad, the author presents a comprehensive modular technology implemented through complete, autonomous, and standardized technological modules configured as the following integrated system:

Figure 1. *Diagram of the Nine Principal Modular Technological Configurations Incorporating All Processing Stages and Operations Required for the Formation of a Modular Technological Equipment Complex Intended for the Treatment, Regeneration, and Recirculation of Process Fluids, Including Water and Aqueous Solutions*



Among the modules presented, **Module 5 (Power Supply Unit)** is comparatively universal in its application, whereas the remaining eight modules perform specialized technological functions within the integrated water treatment system.

Module 1 – Sedimentation Module, which may be configured either as a sedimentation column or as a sedimentation tank having a rectangular (parallelepiped) geometry.

Module 2 – Turbo-Aeration Module, which may be implemented in at least two configurations: one utilizing foam generators and another employing an integrated mixing and online homogenization system.

Module 3 – Ion-Exchange Treatment Module, which may be implemented in numerous configurations, one of the most efficient being ion-exchange columns incorporating capsules for ion-exchange resins fabricated from carbon-carbon composite fabrics.

Module 4 – Coagulation Module, utilizing aluminum ions generated within electrochemical reactors equipped with aluminum anodes as the coagulant.

Module 5 – Power Supply Unit, providing electrical power to the technological modules and associated electrochemical processing systems.

Module 6 – Automatic Mechanical Filtration Module, incorporating automatic cleaning of the filtration sections together with online regeneration of the filter elements.

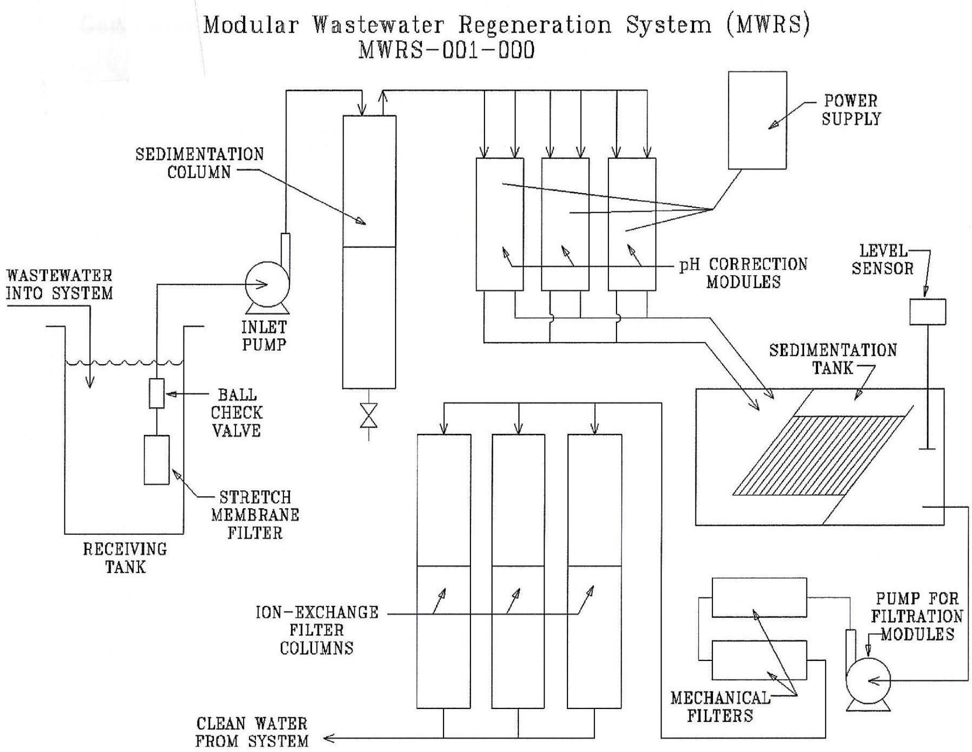
Module 7 – pH Adjustment Module, intended for the regulation and stabilization of the acidity and alkalinity of process fluids.

Module 8 – Reagent-Free Electrochemical Disinfection Module, designed to provide electrochemical disinfection without the addition of chemical disinfectants.

Module 9 – Final Electrochemical Coagulation Module, intended for the final polishing stage of the treatment process through electrochemically induced coagulation.

This modular architecture enables the development of scalable, flexible, and integrated technological systems that can be configured according to the specific requirements of industrial water treatment, process fluid regeneration, and recirculation applications while maintaining high operational efficiency and environmental sustainability.

Figure 2. *Example of a Modular System Configuration for the Regeneration of Process Fluids, Including Water and Aqueous Solutions*



As illustrated in the diagram, the inlet of the system is equipped with a receiving tank incorporating several functional components that perform the preliminary treatment of process fluids that have completed their operational cycle. The incoming liquid first passes through a membrane filter and then, via a check valve, enters the inlet pump, which delivers the process fluid to the sedimentation column. Depending on the required treatment capacity and process flow rate, the sedimentation column may consist of one, two, or three independent sections.

Following the primary sedimentation stage, the process fluid is directed to electrochemical reactors designed to adjust its acidity or alkalinity. These reactors are supplied with electrical power and controlled by a multifunctional power supply unit.

After pH adjustment, intended to establish alkaline conditions that maximize sedimentation efficiency, the fluid enters a specially designed sedimentation module featuring an optimized internal geometry that promotes the separation of sedimentation conglomerates from the liquid within an upward-flow regime.

Upon completion of the sedimentation process, the treated liquid is transferred, under the control of a level sensor, by a centrifugal pump to the automatic mechanical filtration modules, where residual conglomerate particles that have not settled within the sediment layer are removed by mechanical filtration.

Because the mechanical filtration modules operate continuously in an online mode, the discharge pressure generated by the filtration pumps is sufficient to supply the filtered liquid directly to the ion-exchange treatment columns.

Building upon the engineering concepts, technical publications, patent applications, and long-term technological forecasting developed by Ostap Victor Vlad in the field of environmentally sustainable intelligent manufacturing systems, the author of the present study has significantly expanded the technical capabilities and functional characteristics of ion-exchange treatment columns, which deserve further detailed consideration.

Particular attention should be given to the fact that ion-exchange treatment may effectively employ not only synthetic ion-exchange resins but also naturally occurring ion-exchange materials, among which zeolite represents one of the most effective alternatives.

Within the innovative modular architecture of ion-exchange columns proposed by Ostap Victor Vlad, where each column consists of at least two independent modular sections, it becomes possible to combine several ion-exchange materials possessing different exchange capacities within a single treatment column. For example, the upper section may contain zeolite, while the lower section may be filled with a synthetic ion-exchange resin.

The combination of these complementary ion-exchange materials provides highly efficient conditions for the purification, regeneration, and recirculation of process fluids while improving both treatment performance and operational flexibility.

This modular configuration has been developed in accordance with the engineering concepts and inventions proposed by Ostap Victor Vlad, a recognized developer of reagent-free technologies for the comprehensive high-intensity treatment of industrial liquids, including water and aqueous solutions, operating under continuous real-time flow conditions.

Practical implementation has demonstrated that the hierarchical system of technological modules proposed and developed by Ostap Victor Vlad, characterized by narrow technological specialization together with a high degree of operational autonomy, independent technological cycles, and the complete absence of chemical reagents or synthetic activating additives, enables higher-level integrated treatment systems to be constructed from lower-level modular components while maintaining maximum technological and economic efficiency.

Furthermore, because no chemical reagents are introduced into the treatment process, the completion of the regeneration stage allows the online recirculation process to commence immediately. This approach preserves the physicochemical properties and consistently maintains a high level of quality of regenerated process fluids and aqueous solutions while substantially improving the environmental sustainability and operational efficiency of the overall treatment system.

Figure 3. *Modular Treatment System Incorporating an Intermediate Module with a Preliminary Inlet Filter and a Series of Mechanical Filters Installed Downstream of the Intermediate Module and Upstream of the Electrochemical Reactors for pH Adjustment*

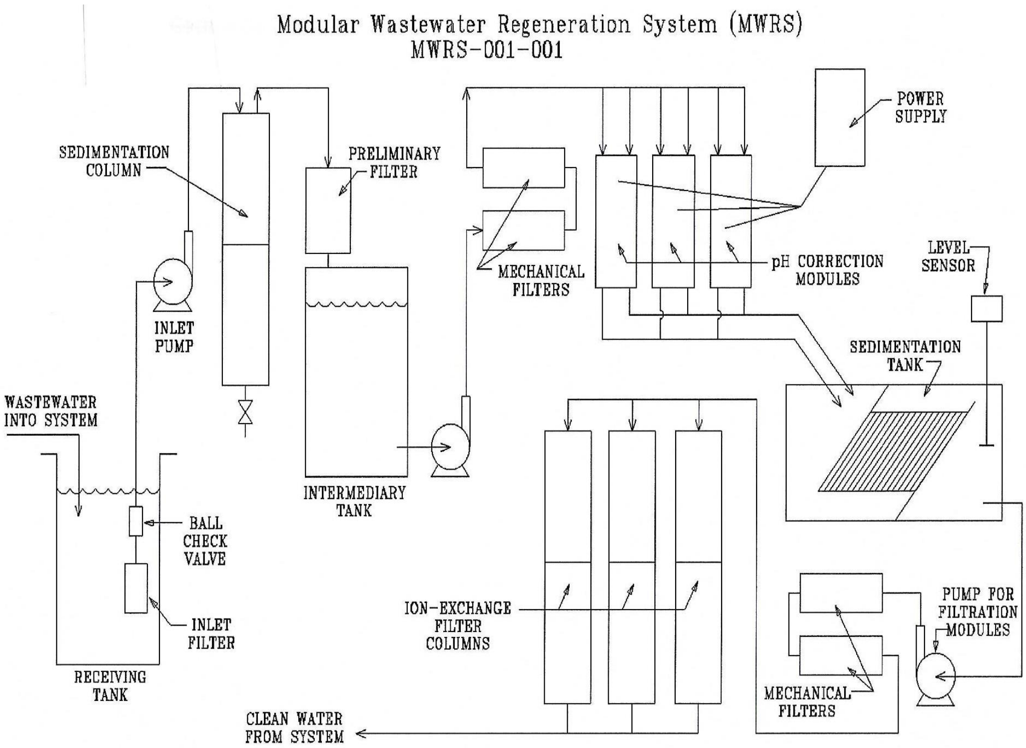
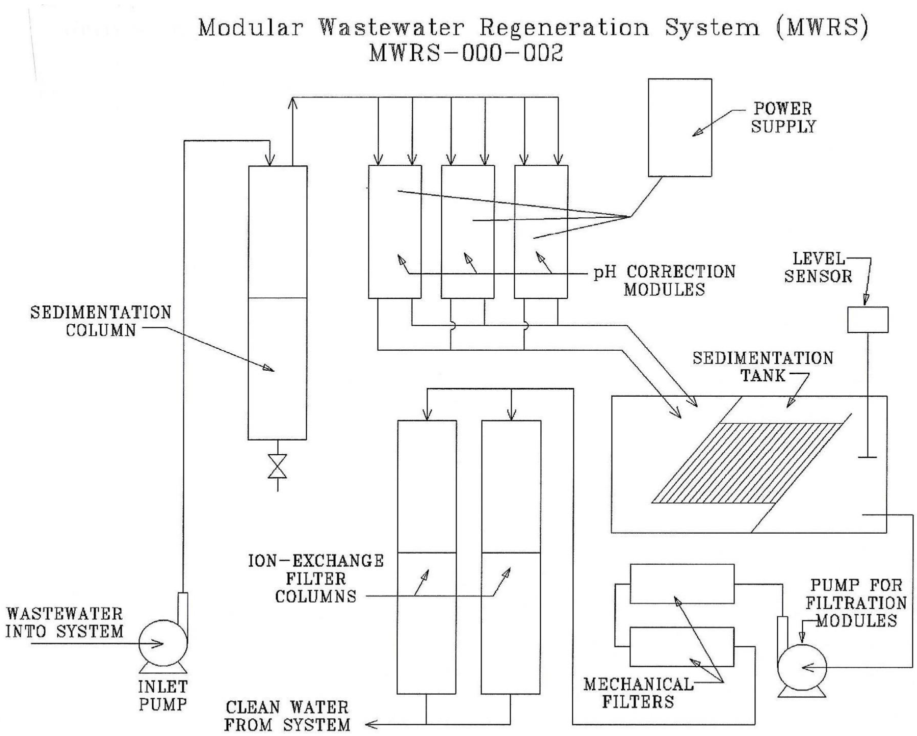


Figure 4. *Compact Modular System Configuration Without Intermediate Technological or Structural Components*



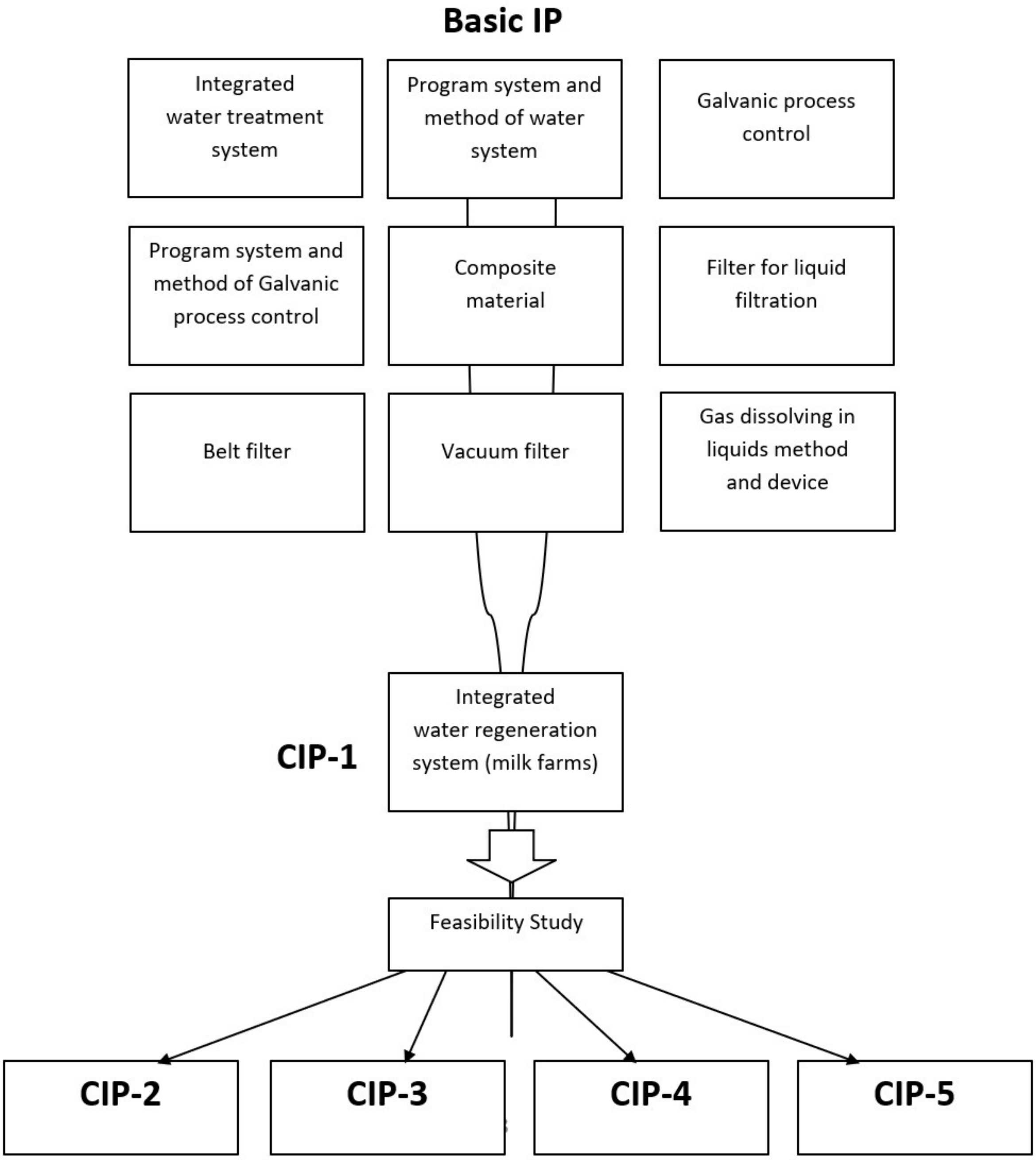
As demonstrated by the figures and diagrams presented above, the hierarchical architecture of vertically integrated modular systems enables the simultaneous resolution of technological and environmental challenges while satisfying the operational requirements of industrial facilities of various types and processing capacities, regardless of the degree of contamination of their industrial waste streams, through their complete regeneration and subsequent recirculation. Furthermore, this modular engineering approach facilitates the gradual transformation of manufacturing facilities with varying levels of operational complexity and organizational flexibility into so-called intelligent manufacturing systems (smart manufacturing facilities), characterized by advanced process automation, environmental sustainability, and integrated technological management.

As illustrated by the presented algorithmic diagram, which has also been developed taking into account the innovative concepts and engineering proposals derived from the inventions and scientific publications of Viktor-Vlad Ostap, a total of fourteen functional entities are represented. Each of these entities constitutes an integrated assembly of technological modules, themselves composed of autonomous modules belonging to lower combinatorial hierarchy levels.

Each of the presented modules constitutes an independent subject of patent protection, while every possible combination of these modules likewise represents a patentable technological solution and a legitimate subject for further continuation patent applications in accordance with the applicable patent legislation of the United States.

At present, industries utilizing water treatment technologies face numerous challenges that prevent auxiliary water treatment operations from achieving the same level of efficiency as the principal technological processes. The most significant challenges include:

- the continuous reduction in available water resources suitable for industrial process applications;
- the progressive deterioration of the quality of natural water resources available for technological use;
- the steadily increasing cost of industrial water resources;
- increasingly stringent environmental regulations governing the quality of wastewater discharged into municipal sewage systems, resulting in higher wastewater treatment costs;



- continuously increasing quality requirements for process water utilized in industrial production;
- the ongoing introduction of new synthetic, composite, and organic materials accompanying the development of advanced manufacturing technologies, requiring continuous modernization of water treatment facilities or the development of treatment systems possessing an exceptionally broad operational range, thereby substantially increasing both equipment costs and the overall cost of water treatment processes;
- the existence of numerous industrial facilities operating with conventional technologies whose water treatment equipment has reached the end of its service life, while replacement is either economically prohibitive or technically impractical.

Patent and Licensing Status of the Proposed Technologies and Patentability of the Proposed Technological Methods

Based on preliminary engineering analysis and patent searches, the following subjects have been identified for future patent applications:

- an integrated modular system for advanced treatment of water and aqueous solutions, together with its associated method of use;
- a comprehensive method for the treatment of water and the technological modules implementing the proposed method;

Integrated water treatment technology

- a method for the electrolytic extraction of metals from flowing water or aqueous solutions and electrode cells for implementing the method;

- a method for the aerodynamic foaming of water in a continuously flowing stream together with a foam generator for implementing the method;
- an integrated filtration method combining mechanical filtration, ion-exchange treatment, and biosorption;
- an electrocoagulation electrode cell incorporating coaxial electrodes;
- an electrocoagulation electrode cell incorporating a continuously moving belt cathode;
- an electrochemical cell for pH adjustment utilizing assemblies of polarizable soluble electrodes;
- an electrochemical cell for pH adjustment utilizing three-dimensional porous electrodes;
- an electrochemical cell for pH adjustment utilizing continuously moving belt electrodes;
- an electrochemical disinfection cell together with associated electrode assemblies for implementing the proposed disinfection method.

For each proposed patent application, prototype technologies and analogous engineering solutions have been identified from among the innovative developments and inventions of *Ostap Victor Vlad*, the originator and principal developer of the proposed technological concepts. Based on the results of the preliminary patent search and structural patentability analysis, the above-listed technical solutions have been determined to possess full patentability.

Building upon the foregoing concepts, and in combination with the proposed vertically integrated modular architecture, it becomes possible to establish the block diagram of an integrated technological complex in which the flexibility and selectivity of each technological process are achieved at the level of every individual module belonging to the lowest tier of the hierarchical modular structure.

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MODERN DIGITAL TECHNOLOGIES IN THEIR INTERACTION WITH TRIZ (Modern Digital Technologies with Elements of Artificial Intelligence and Artificial Neural Networks in Their Interaction with TRIZ and ARIZ)

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Abstract

This article examines the application of modern intelligent multidisciplinary digital technologies incorporating elements of artificial intelligence and artificial neural networks in the development of innovative engineering solutions based on the principles of TRIZ and ARIZ. Particular attention is devoted to the analysis of the psychological, technological, and marketing factors that influence the transformation of inventive concepts into commercially viable products under conditions of rapidly evolving digital technologies. The article substantiates the necessity of adopting a fundamentally new multidisciplinary approach to engineering design in response to the shortening innovation cycle, increasing product complexity, and rising costs of prototype development and testing. The proposed concept integrates systematic inventive problem-solving methodologies with intelligent digital technologies to identify non-obvious auxiliary innovative functions capable of improving product competitiveness and commercial potential. It is concluded that only the comprehensive integration of TRIZ/ARIZ methodologies with artificial intelligence, artificial neural networks, and multidisciplinary digital technologies can significantly enhance the efficiency of innovation processes and increase the probability of successful commercialization of advanced technical solutions.

Keywords: *Digital Technologies; TRIZ; ARIZ; Intelligent Multidisciplinary Digital Technologies; Product Marketing Aspects; Simulation of Used Structural Materials; Innovation Analysis; Paradoxes of Dynamic Fuel Component Mixing; Stereotypes and Associated Psychological Barriers*

Introduction

All inventors know that sometimes technical solutions are created that, under real-world conditions, function effectively and solve multiple problems – problems that, even at the conceptual stage, prompted the inventor to conduct innovative analysis and triggered purposeful creative activity. At the same time, there are contrived and seemingly obvious technical solutions that are developed in isolation from reality and solve absolutely nothing, except for serving as a means of pursuing ambitious claims to some kind of (usually useless) idea in the field of technology and engineering.

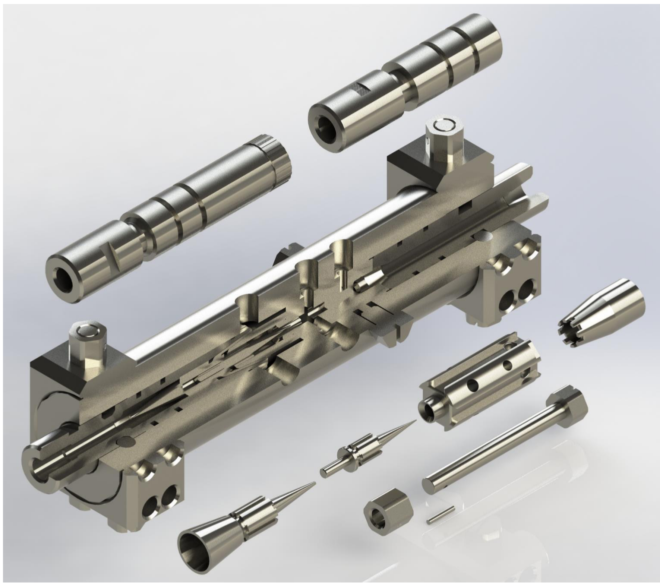
Figure 1. *An example of modern innovative design with full simulation of the used structural materials and their properties and performance characteristics, including the type of mechanical processing and finish type*

Moreover, technical solutions that arise within a specific local domain inevitably affect, either directly or indirectly, established technical stereotypes and the psychological barriers that have emerged, and continue to emerge, based on these stereotypes. These barriers often obstruct the resolution of technical and technological contradictions that evolved from these psychological foundations.

Twenty years ago, the necessity for the second group of inventions – and the equally important need to consider the influence of psychological barriers – was often justified by their auxiliary role: serving as a basis for selectively identifying the most effective and non-obvious technical solutions from the total pool of initiated technical and creatively combined ideas.

In modern designs and technological solutions, novelty is no longer a reflection of a single technical discipline, but rather the result of a combination of integrated disciplines, including electronics, microelectronics, advanced materials science, fiber optics, and laser technology. This necessitates an evaluation of obviousness or non-obviousness from multiple perspectives – an assessment that can only be adequately performed by narrow-domain experts working in collaboration with specialists in complex systems integration.

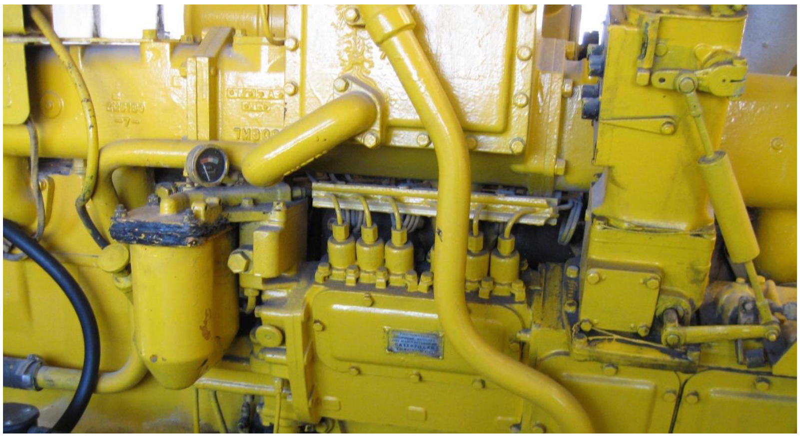
Figure 2. *An example of modern innovative design utilizing sectional views, along with a technical and innovative analysis of the level and credibility of the qualification of non-obviousness for all components of the device, as well as the same level of non-obviousness in the functional characteristics of assembly associations and the resulting commercial advantages of these characteristics*



Over time, each technical discipline develops a set of typical solutions that gradually become entrenched as stereotypes, familiar to nearly all practicing professionals in the field.

Such stereotypes become embedded in everyday practice, and any changes in design or technology tend to encounter certain barriers, which, over time, evolve into well-formed technogenic psychological barriers. In this context, effective participation in the synthesis of innovative ideas – especially through brainstorming – and the refinement of those ideas and their innovative combinations toward the boundary of the Ideal Final Result may encounter, and often do encounter, stereotypical psychological barriers. Even when part of a group generates technically viable proposals that are non-obvious to the average specialist in that specific field, such ideas are unlikely to be immediately and unequivocally accepted. They are often rejected, particularly at the early stages of development.

Figure 3. *The figure shows a view of a diesel generator being modernized by integrating a device into its fuel system for mixing and homogenizing the fuel mixture – diesel fuel with methanol*



The process of developing a project for integrating a device for dynamic fuel component mixing into the fuel supply systems of thermal equipment (including boilers of all types)

Figure 4. *The figure shows a device for online mixing and homogenizing fuel mixtures before injection into the combustion chamber of a thermodynamic system*

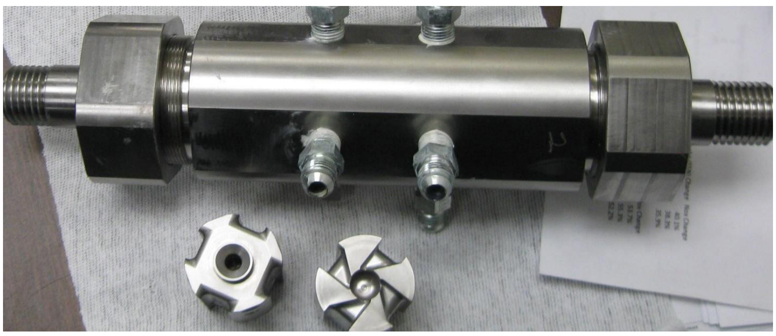


Figure 5. *The figure also shows a device for online mixing and homogenizing fuel mixtures before injection into the combustion chamber of a thermodynamic system, including internal components*

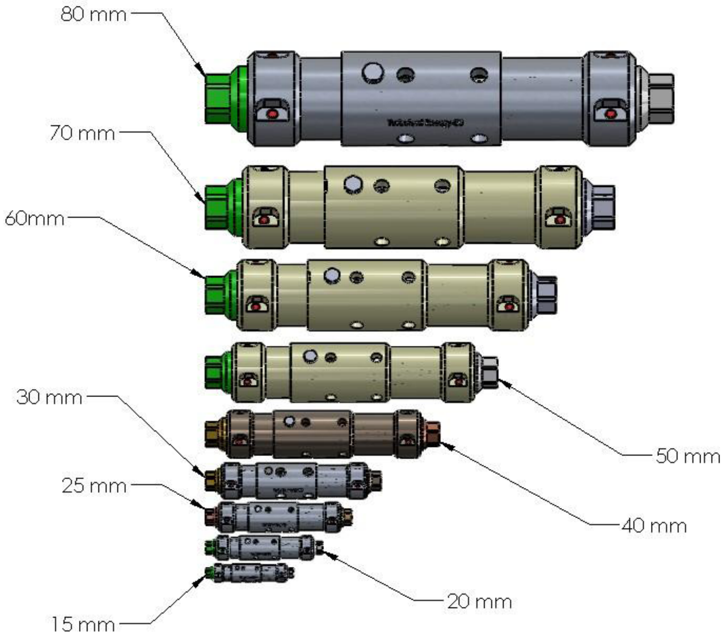


Figure 5. The figure shows a range of sizes for devices used for online mixing and homogenizing fuel mixtures before injection into the combustion chamber of a thermodynamic system.

All 9 sizes of devices for online mixing and homogenizing fuel mixtures before injection into the combustion chamber of a thermodynamic system have an equivalent internal structure and a uniform design of internal components.

Figure 6. *The figure shows devices for monitoring the parameters of the obtained fuel mixture*

For boilers, the device must include a nozzle to ensure a higher level of adaptation to the fuel supply systems for 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 can be presented as a standalone product or a compact burner.

This applies equally to boilers that use diesel fuel and to those that use natural gas as fuel.

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

For devices designed for dynamic mixing of fuel components, where liquid fuel plays a dominant role, there are several paradoxes inherent in all such applications. The first paradox is characterized by the fact that in the pipeline, with the same cross-section, the same initial pressure, and the same initial flow rate of the incompressible liquid component, a ring-shaped vacuum zone is formed without any additional energy consumption.

Figure 7. *The figure shows the appearance of the fuel mixture after structure restoration*

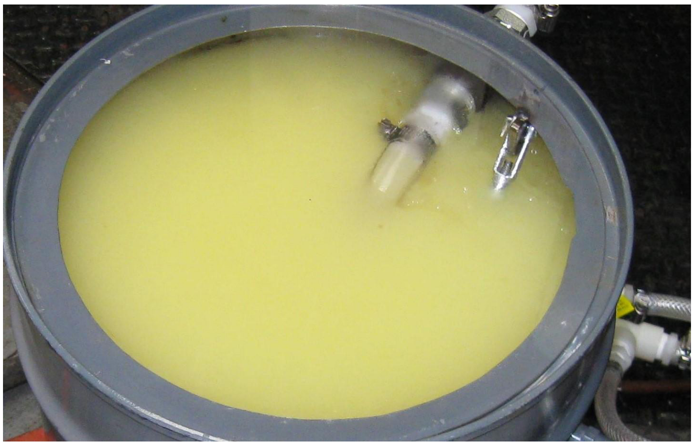


Figure 7–1. *The figure shows the internal structure of the device*

Figure 8. *The figure shows the appearance of the fuel mixture before structure restoration*

This zone represents a kind of 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 fluid to a compressible working fluid.

Figure 9. *The figure shows systems using artificial intelligence and artificial neural networks applied during the qualification testing of the technology and device*

The third paradox is that at the point of change in the physical properties of the flow, the flows of the liquid and gaseous components are coaxial, with the liquid component flow enveloping the gaseous component flow.

Figure 10. *The figure also shows systems using artificial intelligence and artificial neural networks applied during the qualification testing of the technology and device*

The directions of flow at the indicated point coincide.

The fourth paradox is that in the zone, which represents the boundary between the incompressible part of the flow and the compressible part, there is a deep vacuum or rarefaction. This occurs under conditions where two coaxial flows each create a ring-shaped rarefaction zone: one created by the incompressible liquid flow, and the other created by the compressible air flow.

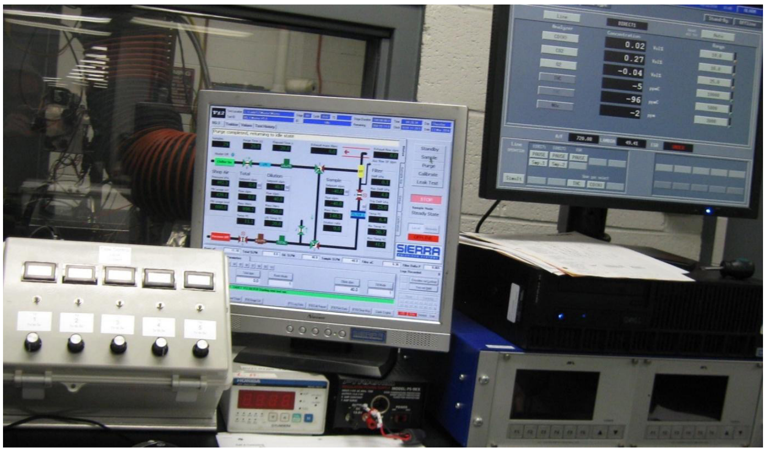
Both of these zones are coaxial to each other, and the thickness of the flow in them does not exceed 100 micrometers for the liquid and 25 micrometers for the gas.

The linear velocity in each of the flows in the rarefaction zone exceeds 100 meters per second, with no additional energy sources being used in the process.

The fifth paradox is that the flow of the mixture 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 velocity of the flows, in the boundary zone separating the incompressible liquid and the compressible mixture, numerous capsules of composite fuel are formed. More than 27 million spherical capsules, each with a diameter not exceeding 50 micrometers, are present per liter of mixture or fuel composite.

Figure 11. *The figure also shows fragments of the system using artificial intelligence and artificial neural networks applied during the qualification testing of the technology and device*



In these capsules, the core is a compressible element – air – and the shell is an incompressible element – liquid or a homogeneous mixture of liquids.

The seventh paradox is that when necessary, a liquid additional component of the fuel composite, such as water, can be drawn into the boundary zone between the compressible and incompressible parts of the flow.

At the same time, no additional energy is required to draw water into the liquid fuel component flow and mix it; only the energy of the liquid fuel component flow is needed.

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ADDITIONAL ADVANTAGES OF THE CONTACTLESS ELECTROMAGNETIC RESONANCE SPECTROSCOPY METHOD IN MEASUREMENTS IN THE SMART FAMILY PHYSICIAN'S OFFICE (Additional advantages in the smart family physician's office when using the contactless electromagnetic resonance spectroscopy method for measurement and online integrative analysis of the state of viral infection in the body of the measurement subject, as well as for continuous monitoring of the stages and phases of viral infection development under real-world complex conditions inherent to the measurement subject's body)

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Abstract

This article examines the additional advantages of the contactless electromagnetic resonance spectroscopy method for measurement, online integrative analysis of viral infection, and continuous monitoring of its development under real-world conditions. Particular attention is paid to the method's extremely low energy consumption, which significantly reduces electronic noise while improving the sensitivity and accuracy of measurements.

The article also discusses the design features of the sensor module, including the use of planar and three-dimensional coils, and highlights the potential of the technology for detecting viral infections, assessing antibody activity, and monitoring biological, chemical, and physical parameters in medical and laboratory applications.

The proposed approach combines high sensitivity, contactless measurement, and real-time monitoring, providing a foundation for next-generation intelligent diagnostic systems with broad applications in medicine, biotechnology, and continuous monitoring.

Keywords: *Smart family physician's office; Contactless electromagnetic resonance spectroscopy method; Measurements in the smart family physician's office; Additional advantages in the smart family physician's office when using the contactless electromagnetic*

resonance spectroscopy method for measurement; Additional advantages in the smart family physician's office when using the contactless electromagnetic resonance spectroscopy method for measurement and online integrative analysis of the state of viral infection in the body of the measurement subject, as well as for continuous monitoring of the stages and phases of viral infection development under the real-world complex conditions of the smart family physician's office

Additional advantages of the contactless electromagnetic resonance spectroscopy method in measurement and online integrative analysis of the state of viral infection in the body of the measurement subject, as well as in the continuous monitoring of the stages and phases of viral infection development under the real-world complex conditions inherent to the body of the measurement subject.

As indicated in the description of the contactless electromagnetic resonance spectroscopy method, one of the most important distinguishing characteristics of the proposed method is its extremely low energy consumption during the measurement process – approximately 1,000 times lower than that of contact-based methods.

As a result, the generation of electronic noise is virtually eliminated, thereby increasing both the sensitivity of the measurement process and the accuracy of the measurement results.

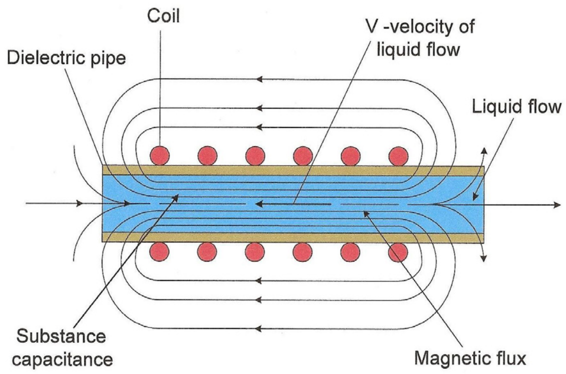
For obtaining and selectively extracting an integral measurement parameter, the above-mentioned advantages make it possible to perform approximately 1,000 input signal variations during the measurement process, differing in both frequency and amplitude (see the appendices for examples).

The design of the sensor in the form of a planar coil with different numbers of active layers has a significant influence on the accuracy and sensitivity of the measurement process. The penetration depth of the probing signal depends on the number of active layers (for example, one layer – penetration depth of 2 millimeters, two layers – penetration depth of 10 millimeters, and so on).

In addition, the proposed method makes it possible to combine different coil configurations within the sensor module – using both a three-dimensional coil and a planar coil in the same sensor, which significantly expands the functional range of monitoring and analytical processing of the measurement results.

Thus, the proposed method makes it possible to measure both the presence of a viral infection and the occurrence and level of antibody activity.

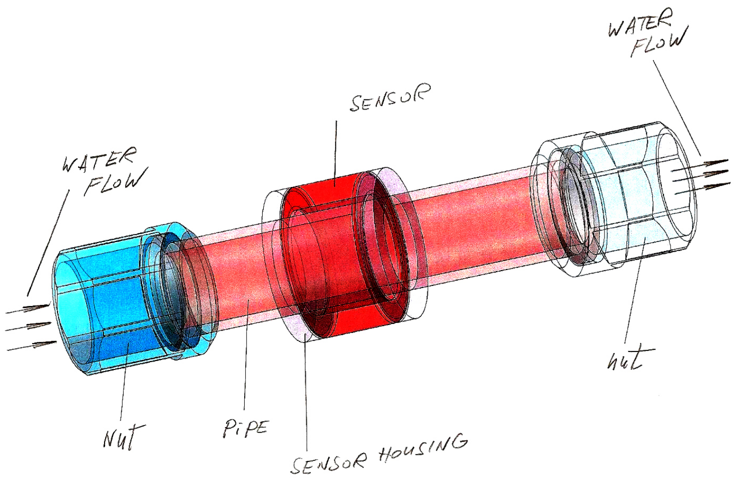
Figure 1.



Applications derived from the proposed monitoring scheme:

- Monitoring of the physical and chemical parameters of a liquid flowing through a pipeline.
- Monitoring of the biological parameters of a liquid flowing through a pipeline.
- Monitoring of the flow rate of a liquid flowing through a pipeline.
- Monitoring of the presence of heavy metal ions and their equivalents in a liquid.
- Monitoring of the presence of bacteria in a liquid.
- Monitoring of the presence of viruses in a liquid.
- Monitoring of the presence of fatty contaminants, somatic cells, and their equivalents in a liquid.
- Monitoring of the acidity levels of a liquid flowing through a pipeline.
- Monitoring of the calorimetric parameters of a liquid flowing through a pipeline.
- Monitoring of the presence of toxic substances and poisons in a liquid flowing through a pipeline.

Figure 2.



The sensor system designed according to the proposed scheme can be installed on any water supply pipeline, process pipeline, specialized technological equipment, and in testing and measurement laboratories.

The proposed sensor system can also be implemented in a portable configuration and can serve as a means for rapid local monitoring and control.

Figure 3.

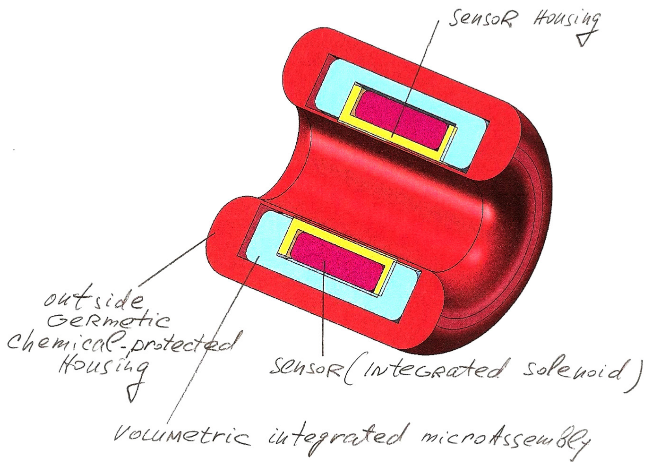
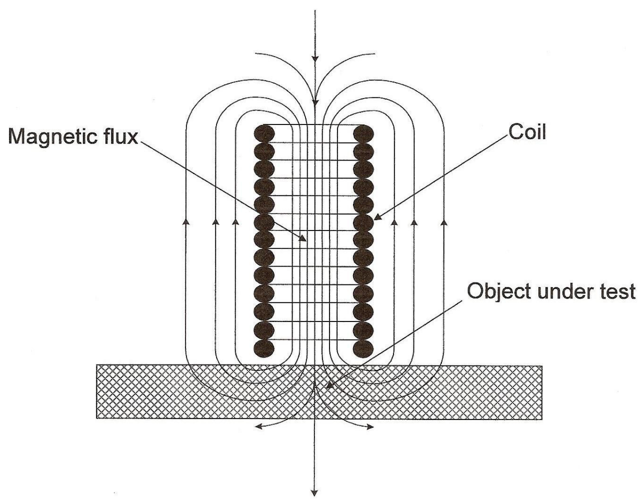


Figure 4.



The sensor system designed according to the proposed scheme can also be used in autonomous monitoring modules for online real-time monitoring and control.

These may include capsules for monitoring the parameters of gastric juice, as well as capsules intended for use in colonoscopy and endoscopy.

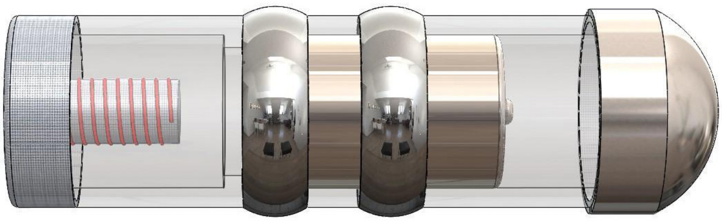
The same system can also be used as a technological witness in closed chemical and electrochemical processes.

The sensor system designed according to the proposed scheme, but without a central opening, can also be used in autonomous monitoring modules for online real-time monitoring and control, including applications in medicine and animal husbandry.

These may include capsules for monitoring the parameters of gastric juice, as well as capsules intended for use in colonoscopy and endoscopy.

The same system can also be used as a technological witness in closed chemical and electrochemical processes in which the central channel may be blocked by solid or amorphous particles contained in the liquid.

Figure 5.



The system shown in the model, designed according to a similar scheme, may be equipped with a dedicated battery and a radio transmitter for transmitting the measurement results and system analysis data to a mobile phone or a processor.

Figure 6.

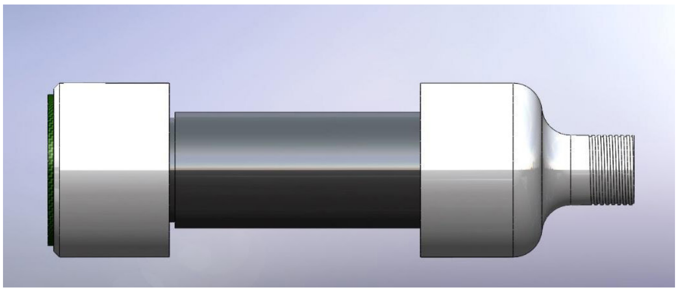
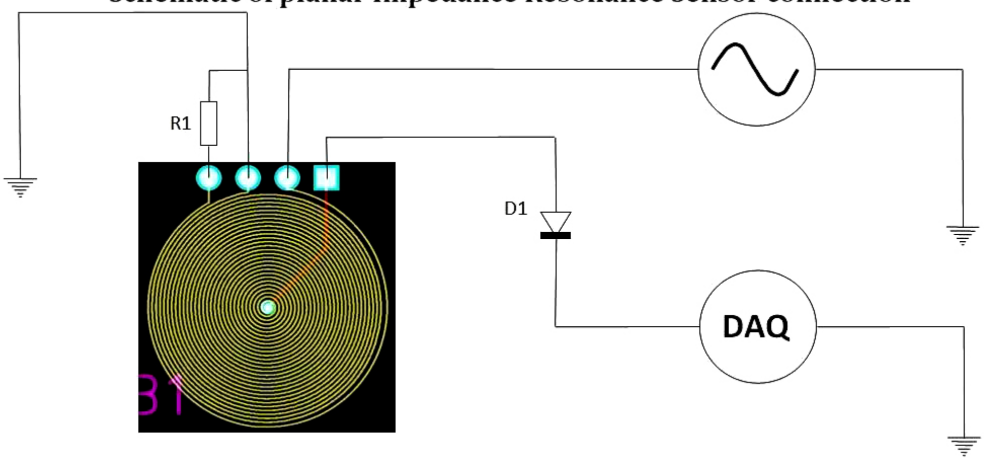


Figure 7.

Schematic of planar Impedance Resonance Sensor connection



The system shown in the diagram, employing a planar coil as the sensor, provides significant operational advantages and can also be used as a scanning measuring device.

This design is ideally suited for mass production, and its applications include use as a personal device, as an instrument for a physician's office, and as a laboratory testing and measurement system.

Figure 8.

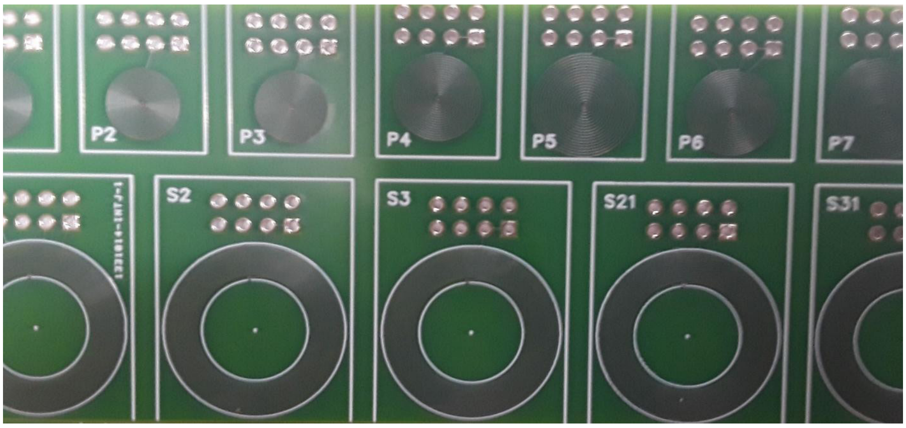


Figure 9.

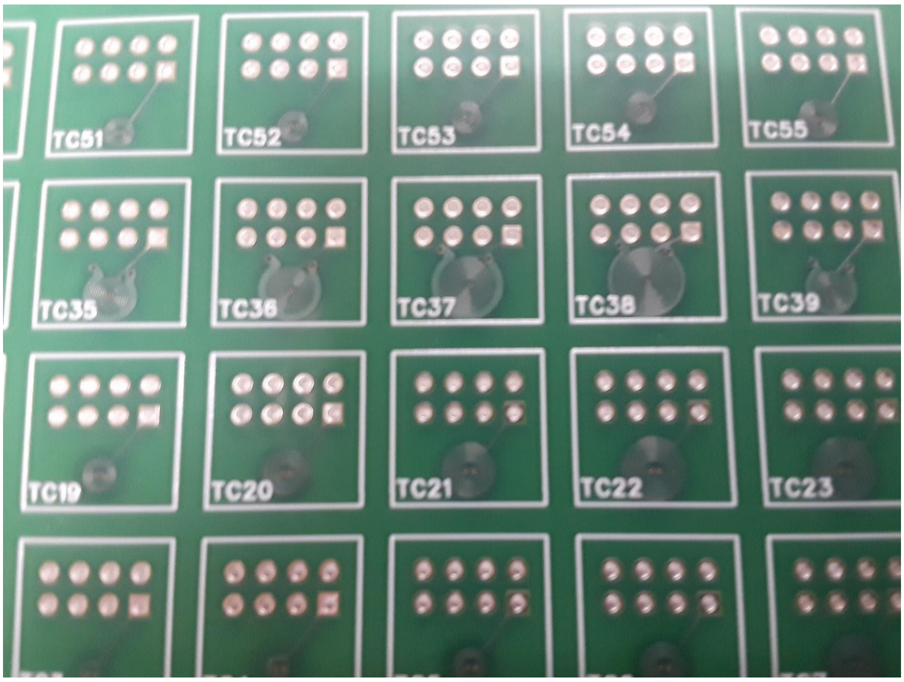


Figure 10.

Appendix 1.
Potential applications of electromagnetic spectroscopy in multifunctional Sensor Technology in medicine and biology.

I. Measurement of the concentration and composition of components in liquids.

These include mixtures of both solutions and dispersed systems: emulsions, suspensions, and biological fluids (blood, milk, lymph, urine, etc.). Due to the high sensitivity of the proposed design options for sensors, the proposed technology can be widely used:

1. In the pharmaceutical industry in technological processes for the production of medicines;
2. For laboratory and off-laboratory analyzes of biological fluids: blood, milk, urine, etc .;
3. In medical, technical and food microbiology for monitoring the concentration of microorganisms and the presence of viruses, including the corona viruses.

II. Measurement of the electromagnetic impedance of biological tissues of the body.

Currently, the measurement of the impedance of biological tissues at different frequencies of alternating current is widely used in diagnostics, as well as in biological and medical research.

For example, a significant increase in tissue impedance at low frequencies can detect inflammation in the early stages. Some thyroid diseases are diagnosed by a change in the phase angle between current and voltage.

Electro – impedance mammography is an effective method for early diagnosis of breast cancer.

Measuring the impedance of the skin helps to diagnose skin diseases, for example, to detect unpainted malignant melanoma and also to identify foci of contamination of the surface of the skin of the corona viruses.

To identify the pathology of the internal organs, an endoscopic impedance measurement can be used. This also includes a non-invasive blood test, for example, for the presence of high sugar levels, and an analysis of the state of lymphatic fluid.

In all the fields of application of impedance measurements listed above, the technology of electromagnetic spectroscopy can contribute, significantly increasing the sensitivity of such measurements.

In addition, the use of these sensors can detect the presence of a corona of viruses in the throat of a person in the initial stages of infection.

The use of methods and technologies of electromagnetic spectroscopy in integrated biosensors.

The term "biosensor" is usually understood as a device in which biological material: (enzymes, tissues, bacteria, yeast, antigens / antibodies, liposomes, organelles, receptors, DNA, viruses, including corona viruses), directly respond to the presence of a signal from of the proposed sensor and generates a resonant signal functionally associated with the presence and concentration of this component.

In this case, using the proposed device implements a fundamentally new way of obtaining information about the chemical composition of the solution.

The presence of a biomaterial with unique properties in the solution allows high selectivity to determine the desired compounds in a complex mixture, without resorting to any additional operations associated with the use of other reagents, concentration, etc. (hence the name – analysis methods without chemical and biological reagents).

Appendix 2.

Brief explanatory description of the sensor module with a single sensor designed as a conventional coil (solenoid).

All structural components of the sensor module are made of irradiated polyethylene or a plastic with similar properties.

In general, the channel through which the measured liquid flows is designed as a communicating vessel with a V-shaped configuration, in which the measured liquid is located in the lower branch of the system.

The description is presented in four figures.

Figure 11.1.

The figure shows, by means of arrows, the flow path of the measured liquid through the combined channel – a communicating vessel in which the sensor is installed on the lower channel with maximum filling of the internal volume at the sensor location.

This arrangement prevents air from entering the measurement zone.

Figure 11.1.

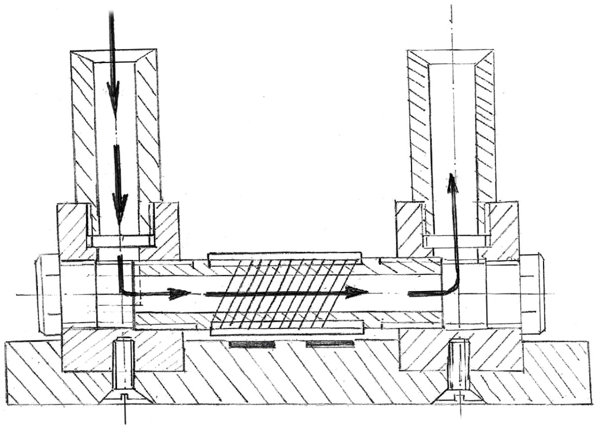


Figure 11.2

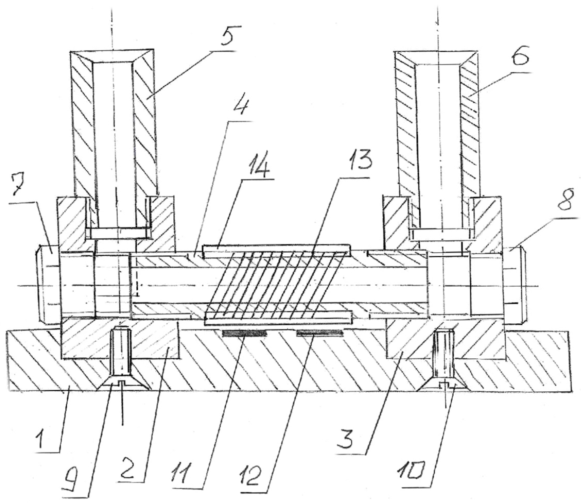


Figure 11.3.

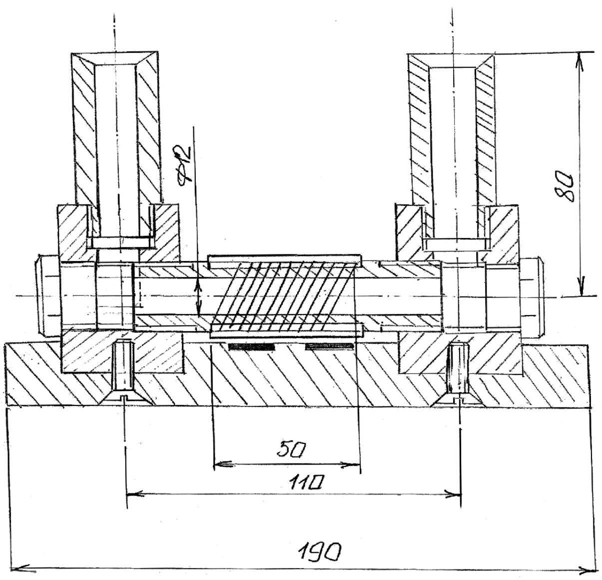


Figure 11.4.

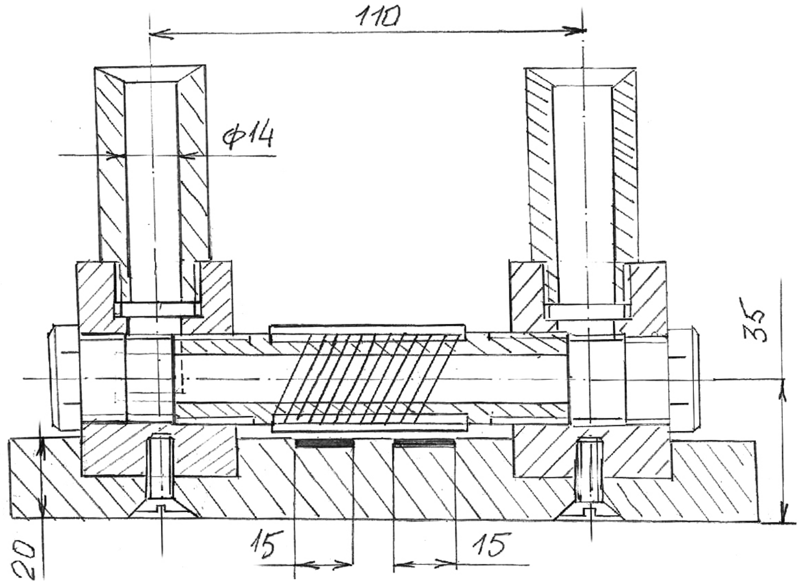


Figure 11.2.

The figure identifies all the components of the sensor module.

The numbered components are as follows:

1 – Base support plate.

The plate is made of plastic and includes two slots for installing and securing the support posts, items 2 and 3, which are fastened to the base support plate using M6 screws, indicated in the figure as items 9 and 10.

Before installing support posts 2 and 3 into the base support plate 1, the sensor working tube, indicated as item 4 in the figure, is screwed into the support posts.

Before assembling the working tube of the sensor (4) with support posts 2 and 3, sensor 13 together with protective shield 14 is mounted onto the working tube.

After that, plugs 7 and 8 and inlet tubes 5 and 6 are screwed into the support posts.

The output from the pulse generator and the input to the monitoring and analytical instrument – the processor (not shown in Figure 11.2.) – are then connected to printed circuit boards 11 and 12.

As a result of the assembly procedure described above, a communicating vessel structure is formed, and after verifying the tightness of all connections, the sensor module can be incorporated into the test unit.

Figure 11.3.

Figure 3 shows the principal overall dimensions of the sensor module with a single sensor.

The length of the solenoid coil is 50 mm.

The distance between the centers of the support posts is 110 mm.

The length of the base of the sensor module with a single sensor solenoid is 190 mm.

The diameter of the measurement channel is 12 mm.

The height of inlet tubes 5 and 6 above the measurement channel with a diameter of 12 mm is 80 mm.

If necessary, this height can be increased.

Figure 11.4.

Figure 11.4. shows the internal diameters of inlet tubes 5 and 6–14 mm.

The height of the center of the measurement channel above the base support plate is 35 mm.

The distance between the axes of inlet tubes 5 and 6 is 110 mm.

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INTEGRATED WATER REGENERATION MODULES FOR SMART HOME INFRASTRUCTURE (Integrated comprehensive water regeneration module with preparation for recirculation; the entire water regeneration process is carried out without the use of chemical reagents, forming the basis of an integrated, comprehensive, multifunctional process for the regeneration of wastewater at a single facility within a smart home infrastructure or its equivalents)

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Abstract

The invention relates to integrated technologies for water treatment, purification, regeneration, and preparation for recirculation within the infrastructure of smart homes and smart mobile homes. The proposed technology is based on a set of autonomous modular units that can be combined in various configurations depending on the operating conditions and the required water treatment objectives.

The integrated system comprises an inlet water treatment module, ion-exchange treatment modules, electrochemical reactor modules with metallic and composite electrode cells operating in single-flow and dual upward-flow configurations, mechanical filtration modules, and final sedimentation modules. The inlet and final treatment modules incorporate foam generation systems, sedimentation systems for foam-separated contaminants, oxygen saturation systems, microbubble and nanobubble aeration systems, and non-contact water quality monitoring devices based on electromagnetic resonance spectroscopy.

The ion-exchange module utilizes sectional columns containing encapsulated synthetic, natural, and biological ion-exchange materials and is equipped with pumps, flow sensors, pressure gauges, check valves, and control valves. The electrochemical treatment modules include electrochemical reactors, power supply units, processor-based control systems, and non-contact real-time acidity monitoring sensors, providing efficient treatment of water and aqueous solutions, including radioactive water.

The proposed modular architecture enables flexible integration of individual treatment technologies into a unified multifunctional water regeneration complex. Each module possesses independent technical novelty while simultaneously providing synergistic performance when operating as part of the integrated system. The invention ensures comprehensive purification, regeneration, and preparation of used water for reuse without the application of chemical reagents, improving treatment efficiency, process reliability, environmental safety, and adaptability to modern smart infrastructure

Keywords: *Module; Water regeneration module; Fundamental modules and core operations of an integrated water purification and regeneration technology for smart home water treatment infrastructure; Chemical-free water regeneration process; Integrated multifunctional water regeneration process; Processor-based control and monitoring system with non-contact real-time pH sensors; Dual upward-flow electrochemical reactor module with metallic electrode cells*

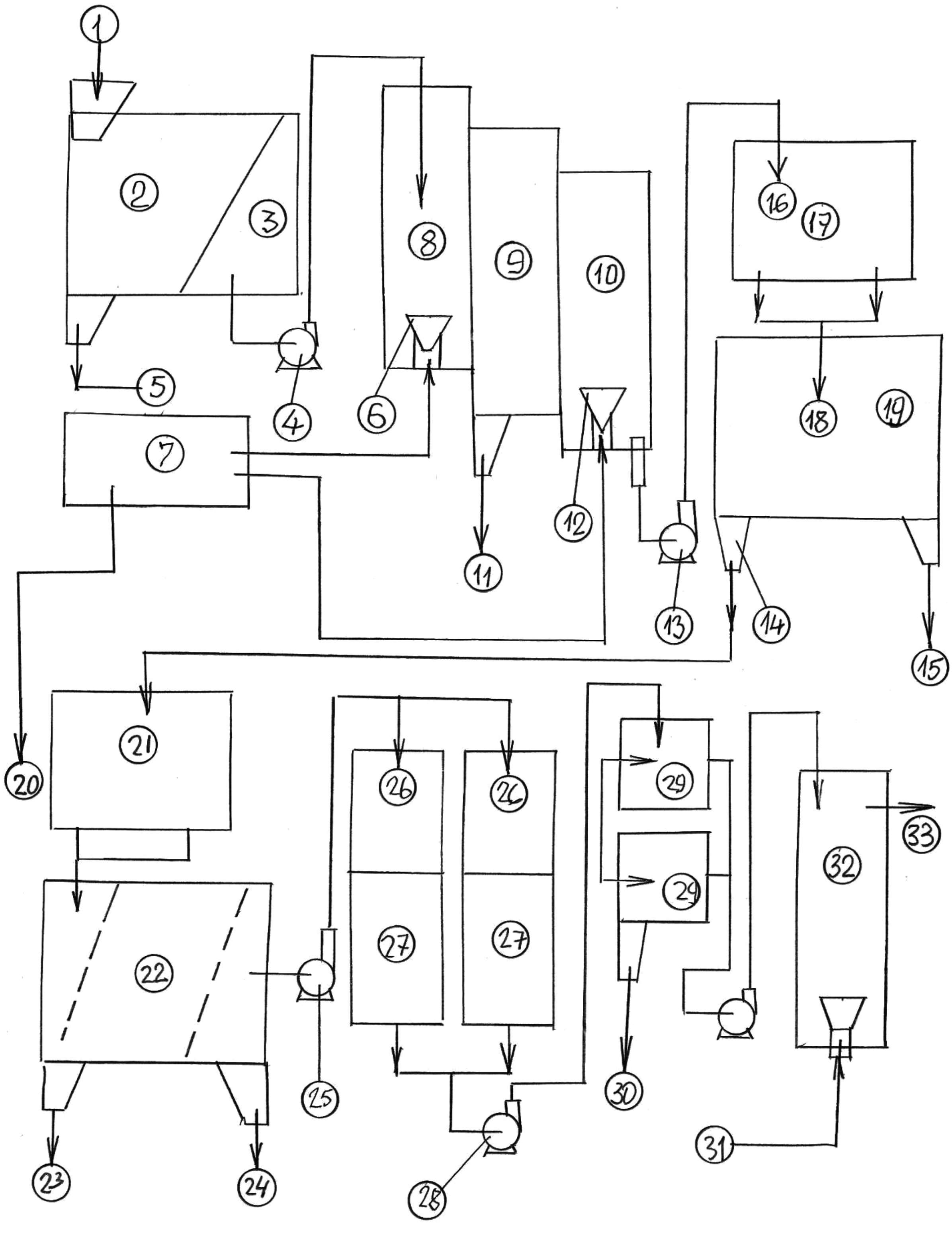
Introduction:

Integrated comprehensive module for water purification and regeneration within a smart home infrastructure system.

The ion-exchange module utilizes sectional columns containing encapsulated synthetic, natural, and biological ion-exchange materials and is equipped with pumps, flow sensors, pressure gauges, check valves, and control valves. The electrochemical treatment modules include electrochemical reactors, power supply units, processor-based control systems, and non-contact real-time acidity monitoring sensors, providing efficient treatment of water and aqueous solutions, including radioactive water. The proposed modular architecture enables flexible integration of individual treatment technologies into a unified multifunctional water regeneration complex. Each module possesses independent technical novelty while simultaneously providing synergistic performance when operating as part of the integrated system. The invention ensures comprehensive purification, regeneration, and preparation of used water for reuse without the application of chemical reagents, improving treatment efficiency, process reliability, environmental safety, and adaptability to modern smart infrastructure.

Figure 1.

Figure 2.



Integrated comprehensive water regeneration module with preparation for recirculation

The entire water regeneration process is carried out without the use of chemical reagents.

The integrated comprehensive multifunctional process for the regeneration of water used at a single facility comprises the following systems:

- Inlet sedimentation without additional treatment;

- Foam treatment with separation of sediment fractions and organic contaminants;
- Separation of the foamed contaminant complex from contaminant-free liquid;
- Secondary aeration of the separated water with dissolution of oxygen to the level of complete saturation;
- Comprehensive treatment of water in an electrochemical reactor operating according to a multifunctional process, including pH adjustment, disinfection, dosing of coagulants or flocculants, and restoration of the water streams to a common pH level;
- Sedimentation within the discharge flow of water containing coagulants or flocculants;
- Repeated multifunctional treatment of the water stream from the sedimentation tank containing coagulants or flocculants according to the following final process: pH adjustment, disinfection, and restoration of the entire treated water stream to the specified common pH level;
- Final sedimentation of all water treated in the second electrochemical reactor;
- Treatment in ion-exchange columns, including sections filled with natural granular zeolite instead of synthetic ion-exchange resin;
- Treatment in automated self-cleaning mechanical filters or membrane filters;
- Final aeration using an aerodynamic vortex foam generator with dissolution of oxygen to the level of complete saturation.

The diagram illustrates:

1. Inlet sedimentation tank for the accumulated sediment, including sediment removal functions and transfer of sediment-free water to the subsequent treatment stage;
2. Sedimentation section of tank 1;
3. Sediment-free water collection section of tank 1;
4. Pump for transferring sediment-free water to subsequent treatment stages;
5. System for removal of water containing accumulated sediment;
6. Aerodynamic vortex foam generator;
7. Compressor supplying three aerodynamic vortex foam generators;
8. Column for vortex foaming of sediment-free water;
9. Column receiving foam discharged from the upper section of column 8, intended for aerodynamic vortex foaming of sediment-free water;
10. Column for vortex foaming, aeration, and dissolution of oxygen in the treated water to the level of complete saturation;
11. Contaminant discharge from column 9 receiving foam from the upper section of column 8;
12. Intermediate aerodynamic vortex foam generator;
13. Pump supplying water, after treatment in column 10 with maximum air content and oxygen dissolved to complete saturation, to the electrochemical cells of the first electrochemical reactor in the direction of water flow.

The proposed technology integrates multiple water treatment processes into a single comprehensive regeneration system, ensuring efficient removal of suspended solids, organic contaminants, microorganisms, and dissolved impurities. The sequential combination of sedimentation, electrochemical treatment, ion-exchange purification, filtration, and final aeration provides a high level of treatment efficiency while maintaining stable water quality throughout the process. A significant advantage of the system is its reagent-free operation, which minimizes the use of chemicals, reduces secondary waste generation, and lowers environmental impact. The incorporation of natural granular zeolite as an ion-exchange material further enhances the sustainability and economic efficiency of the technology by reducing dependence on synthetic resins. Owing to its modular design and integrated multifunctional approach, the system can be adapted for a wide range of industrial and municipal water treatment applications requiring reliable, environmentally friendly, and cost-effective water regeneration.

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SYSTEMS FOR THE REGENERATION AND RECIRCULATION OF PROCESS FLUIDS (Modular systems for the regeneration and recirculation of process fluids, including water and aqueous solutions)

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Abstract

This publication examines the current approaches to the treatment and purification of water used for technological purposes in various industrial sectors. Particular attention is devoted to the existing methods employed for the treatment of water contaminated by products and by-products generated during industrial processes, as well as to their technological capabilities, limitations, and areas of application.

The study analyzes the three principal categories of water treatment technologies currently used in industry. These include chemical reagent-based treatment methods, which remain the dominant technology and account for more than 70% of the water treatment market; chemical-free water treatment and purification methods, represented by several technological modifications with different operational characteristics and covering less than 20% of the market; and various combined treatment technologies that integrate elements of both approaches together with additional process solutions adapted to specific industrial operating conditions. These combined technologies currently account for approximately 10% of the market and continue to expand their range of industrial applications.

Special emphasis is placed on the challenges currently facing water treatment and water conditioning technologies. The publication demonstrates that the requirements imposed on modern industrial production can no longer be satisfied through the application of individual treatment methods or existing combinations of conventional technologies. The continuously evolving technical, environmental, and operational requirements necessitate the development of comprehensive and integrated technological solutions capable of addressing the entire range of water treatment objectives.

Taking these considerations into account, and incorporating a number of innovative concepts developed in recent years, the author proposes an integrated technology for the treatment of industrial wastewater. The proposed solution is based on a sequence of consecutive yet functionally independent processing operations, providing a comprehensive technological approach to the regeneration, purification, and recirculation of industrial process water.

Keywords: *Process fluids; Process fluid regeneration; Process fluid recirculation; Module; Modular architecture; Water; Aqueous solutions; Industrial use of water in technological processes; Water treatment and purification methods; Chemical reagent-based water treatment; Chemical-free water treatment and purification; Current challenges in water treatment and water conditioning; Integrated technology for the treatment of industrial wastewater comprising a series of sequential, yet functionally independent, processing operations*

Introduction

At present, various industries using water for technological purposes apply the following methods for the treatment and purification of water contaminated by products and wastes generated during these technological processes:

Chemical reagent-based treatment. Several modifications of this method, as well as combinations of this method with other technologies, are employed. This method and its modifications are the most widely used, accounting for more than 70% of the water treatment technology market.

Chemical-free water treatment and purification. Several principal modifications of this method are employed, differing in their range of capabilities and performance characteristics. These methods account for less than 20% of the water treatment technology market.

Various combined treatment methods, generally consisting of combinations of the first two methods supplemented by additional technological processes determined by the specific local operating conditions of technology users. These methods and technologies account for approximately 10% of the market and demonstrate a continuing tendency toward wider application.

The problems of water treatment and water conditioning identified to date are, in practice, impossible to solve on the basis of the currently known methods and technologies. The solution must be comprehensive, since partial solutions do not satisfy the requirements of any modern industrial production. Therefore, the application of individual methods or combinations of existing methods does not address all of the new requirements that have emerged and continue to emerge.

Taking the above into consideration, and additionally incorporating innovative concepts developed in recent years, the author proposes an integrated technology for the treatment of industrial wastewater, comprising a series of sequential yet functionally independent processing operations.

More specifically, all stages of water treatment may be represented as successive treatment processes applied to the water. Each of these processes is based on different physical and chemical principles of operation.

In combination with the latest innovative concepts proposed and published by innovative specialists, primarily Dmytro Lysenko, the author proposes an integrated technology that can be implemented by means of complete, autonomous, standardized technological modules configured as follows:

Of all the modules presented, Module 5 – the power supply module is comparatively universal, whereas the remaining eight modules have more specialized fields of application:

Module 1 – Sedimentation Module, which may be configured either as a sedimentation column or as a sedimentation tank having the shape of a rectangular parallelepiped.

Module 2 – Turbo-Aeration Module, which may be implemented in at least two configurations: one employing foam generators and the other utilizing a mixing and in-line homogenization unit.

Module 3 – Ion-Exchange Treatment Module, which may be implemented in a wide variety of configurations, one of the most effective being ion-exchange columns incorporating capsules for ion-exchange resins manufactured from carbon-carbon composite fabrics.

Module 4 – Coagulation Module, utilizing aluminum ions produced in electrochemical reactors equipped with aluminum anodes as the coagulant.

Figure 1. *Illustrates the nine principal modular technological configurations comprising all technological stages and operations required for the formation of a modular process equipment system intended for the purification, regeneration, and recirculation of process fluids, including water and aqueous solutions*

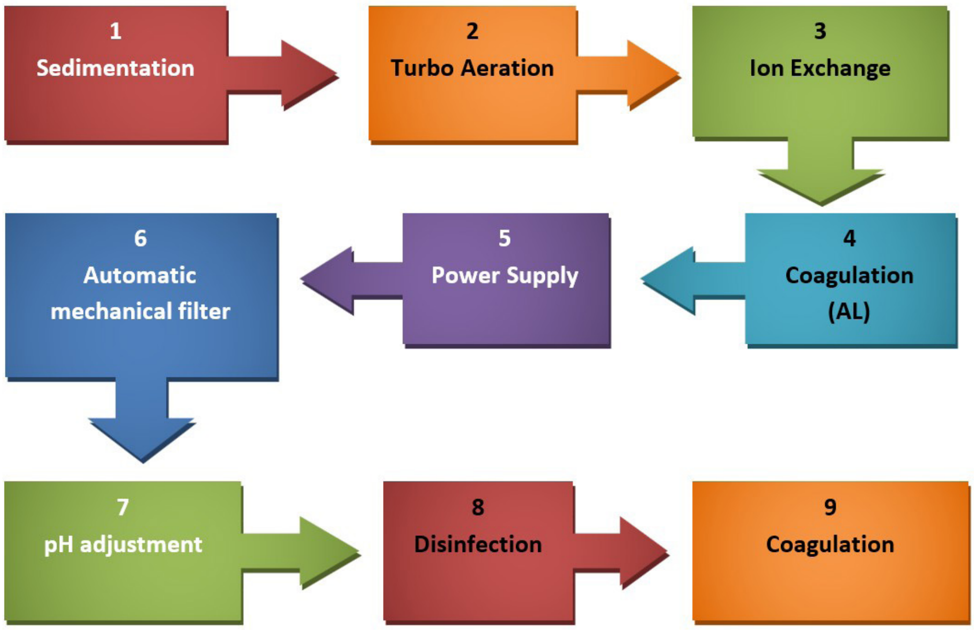
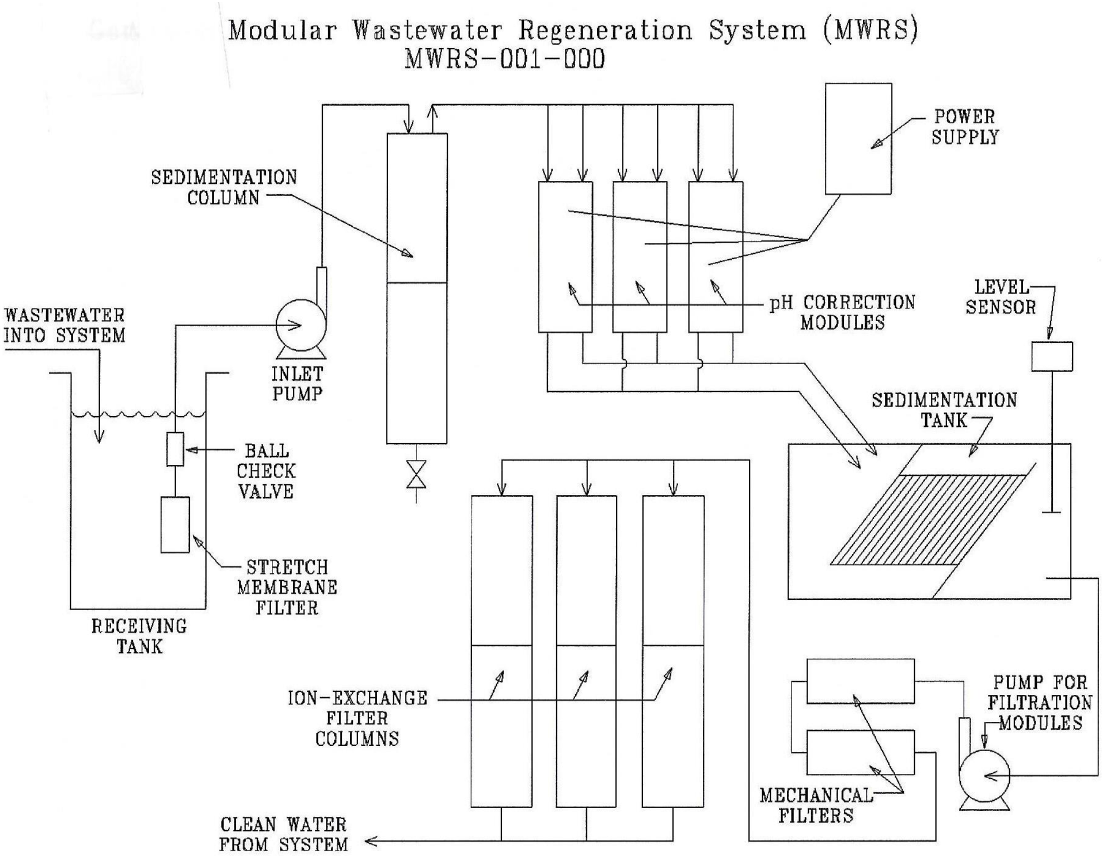


Figure 2. *Illustrates an example of a modular configuration of a system for the regeneration of process fluids, including water and aqueous solutions*



Module 6 – Automatic Mechanical Filtration Module, incorporating automatic cleaning of the filter sections and in-line regeneration of the filter elements.

Module 7 – pH Adjustment Module for the regulation of acidity and alkalinity.

Module 8 – Electrochemical Chemical-Free Disinfection Module.

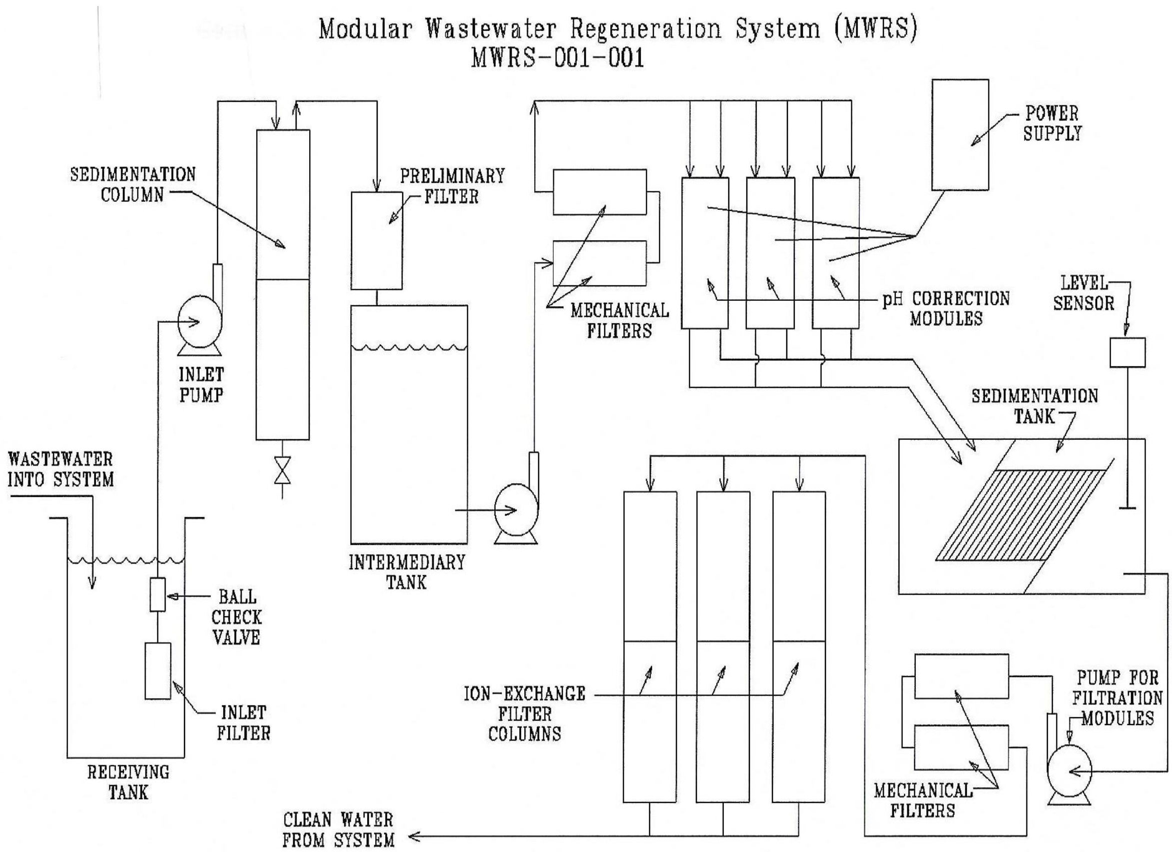
Module 9 – Final Electrochemical Coagulation Module.

As shown in the diagram, the system inlet is equipped with a receiving tank incorporating several components that perform the preliminary treatment of the process fluid after completion of its operating cycle. The fluid passes through a membrane filter connected to the inlet pump via a check valve. The pump delivers the fluid to the inlet of the sedimentation column, which, depending on the process flow rate, may consist of one, two, or three sections.

Following the first stage of sedimentation, the fluid is supplied to electrochemical reactors for the adjustment of acidity or alkalinity. These reactors are controlled and supplied with electrical power by a multifunctional power supply unit.

After pH adjustment, carried out to establish alkaline conditions providing the most favorable environment for sedimentation, the fluid is directed to a dedicated sedimentation module with a special geometric configuration that enables the separation of the formed sedimentation conglomerates from the liquid within an upward flow.

Figure 3. *Illustrates a modular system incorporating an intermediate module with a preliminary filter at the inlet and a system of sequential mechanical filters at the outlet of the intermediate module, positioned upstream of the electrochemical reactors for the adjustment of acidity and alkalinity*



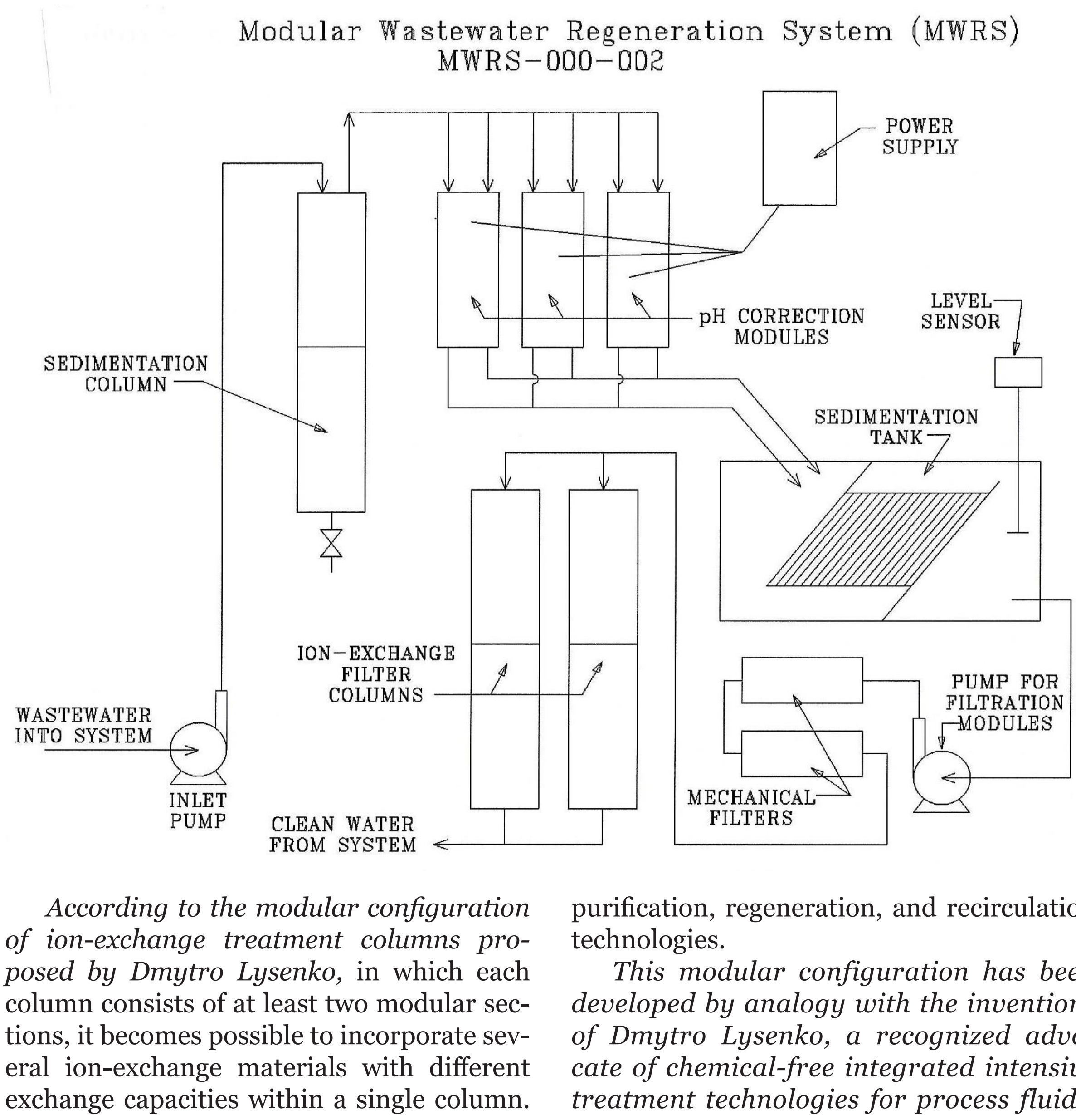
Upon completion of the sedimentation process, the liquid is transferred, upon a signal from the level sensor, by a centrifugal pump to the mechanical filtration modules, where conglomerate particles that have not settled within the sediment layer are removed by mechanical filtration.

Since the mechanical filters operate in an in-line mode, the pressure generated by the filter pumps is sufficient to deliver the mechanically filtered fluid to the inlets of the ion-exchange treatment columns.

Based on the conclusions and proposals presented in the publications and patent applications of Dmytro Lysenko, as well as on his multifunctional forecast for the development of environmentally sustainable engineering and technological systems for industrial process organization, the author of the present publication has significantly expanded the technical capabilities of ion-exchange treatment columns. This aspect warrants more detailed consideration.

It is particularly important to note that ion-exchange treatment should employ not only synthetic ion-exchange resins but also natural materials, among which zeolite represents one of the most effective ion-exchange media.

Figure 4. *Illustrates the most compact modular system, designed without intermediate technological and structural elements*



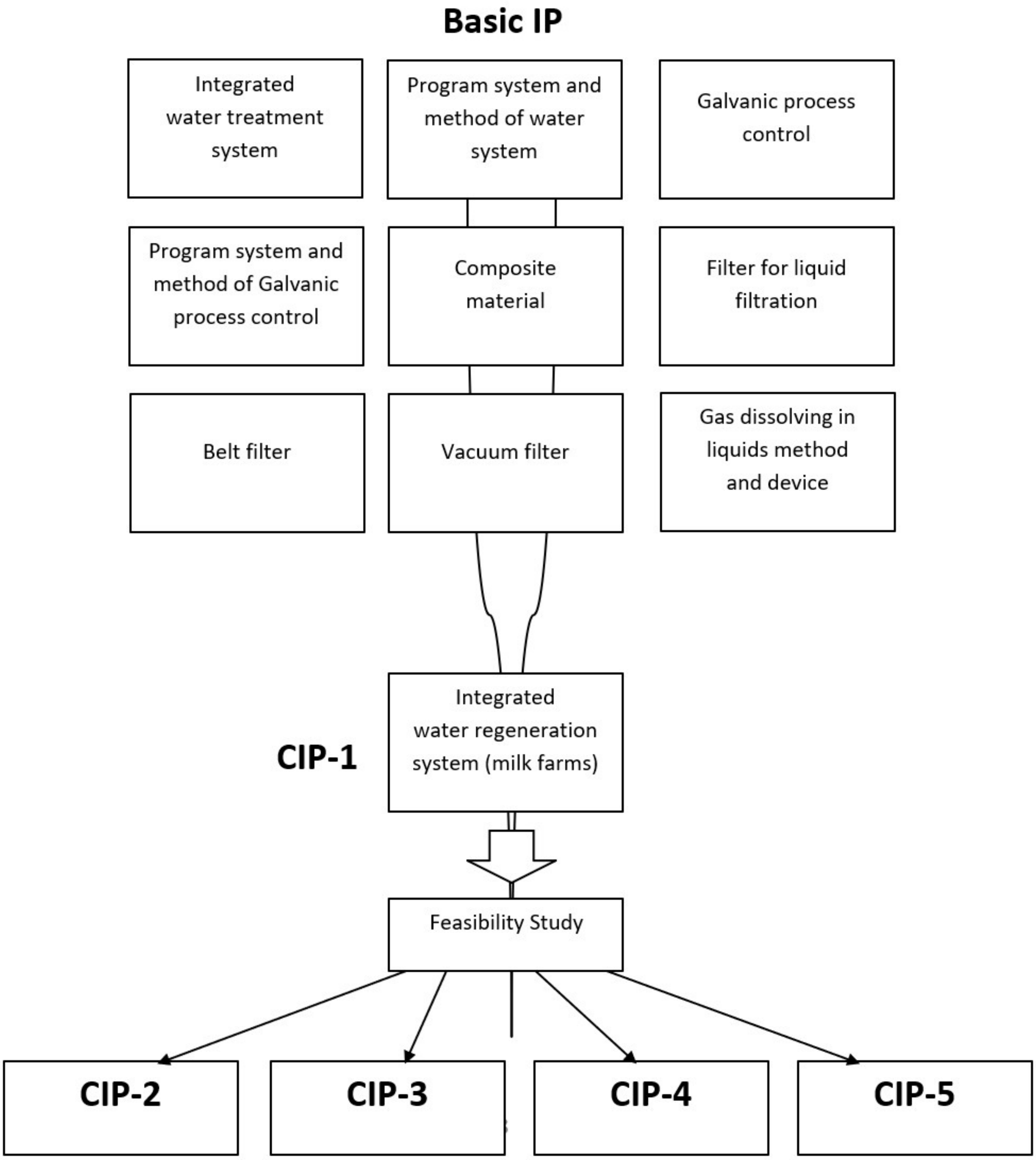
According to the modular configuration of ion-exchange treatment columns proposed by Dmytro Lysenko, in which each column consists of at least two modular sections, it becomes possible to incorporate several ion-exchange materials with different exchange capacities within a single column. For example, zeolite may be installed in the upper section, while ion-exchange resin may be used in the lower section.

The combination of these materials provides the most effective implementation of purification, regeneration, and recirculation technologies.

This modular configuration has been developed by analogy with the inventions of Dmytro Lysenko, a recognized advocate of chemical-free integrated intensive treatment technologies for process fluids, including water and aqueous solutions, operating in real time within directed-flow systems.

Practical application has demonstrated that the hierarchical system of technological modules proposed and developed by Dmytro Lysenko, characterized by narrow technological specialization while remaining highly autonomous, possessing independent production and technological cycles, and operating without the use of chemical reagents or synthetic activating additives, makes it possible to assemble higher-level technological modules from lower-level hierarchical modules while maintaining full economic and technological efficiency.

Furthermore, the absence of chemical reagents introduced into the process makes it possible, immediately upon completion of the regeneration operations, to initiate and successfully perform in-line recirculation, while maintaining a consistently high quality of process fluids and aqueous solutions.



Thus, the presented figures and diagrams demonstrate that the hierarchical structure of vertically integrated modular systems makes it possible to simultaneously achieve a comprehensive solution to technological and environmental challenges while meeting the requirements of industrial facilities of any profile and for any degree of process waste contamination through the complete regeneration and subsequent recirculation of process fluids.

Accordingly, this approach also addresses the challenges associated with the gradual transformation of industrial facilities of all types and levels of organizational flexibility into so-called smart manufacturing systems.

As shown in the presented algorithmic diagram, which has also been developed taking into account the innovative concepts and proposals arising from the inventions and publications of Dmytro Lysenko, a total of 14 objects are considered and presented. Each of these objects, in turn, represents a complex of modules consisting of autonomous modules belonging to a lower combinatorial level.

Each of the presented modules constitutes an independent subject of patent protection, and all possible combinations of these modules likewise constitute independent subjects of patent protection and legitimate objects for subsequent patent continuation in accordance with the current patent legislation of the United States.

At present, users of water treatment technologies face a number of challenges that prevent the efficiency of auxiliary water treatment operations from reaching the level of efficiency achieved by the principal technological processes. The major challenges include:

- the continuous limitation of water resources available for use in technological processes;
- the continuous deterioration of the quality of natural water resources suitable for technological applications;
- the continuous increase in the cost of water resources;
- increasingly stringent regulatory standards governing the quality of water discharged into sewerage systems, resulting in higher wastewater treatment costs;
- continuously increasing requirements for the quality parameters of water used in technological processes;
- the continuous introduction of new synthetic and organic materials as technological processes evolve and existing manufacturing technologies are improved, thereby requiring continuous modernization of water treatment facilities or the development of systems possessing a significantly broader range of operational capabilities, which substantially increases both equipment costs and the overall cost of water treatment processes;
- the existence of a large number of industrial facilities operating with conventional technologies whose equipment has reached the end of its service life, while replacement of such equipment requires considerable investment or, in some cases, is technically impracticable.

Patent and Licensing Status of the Proposed Technologies and Patentability of the Proposed Technological Methods

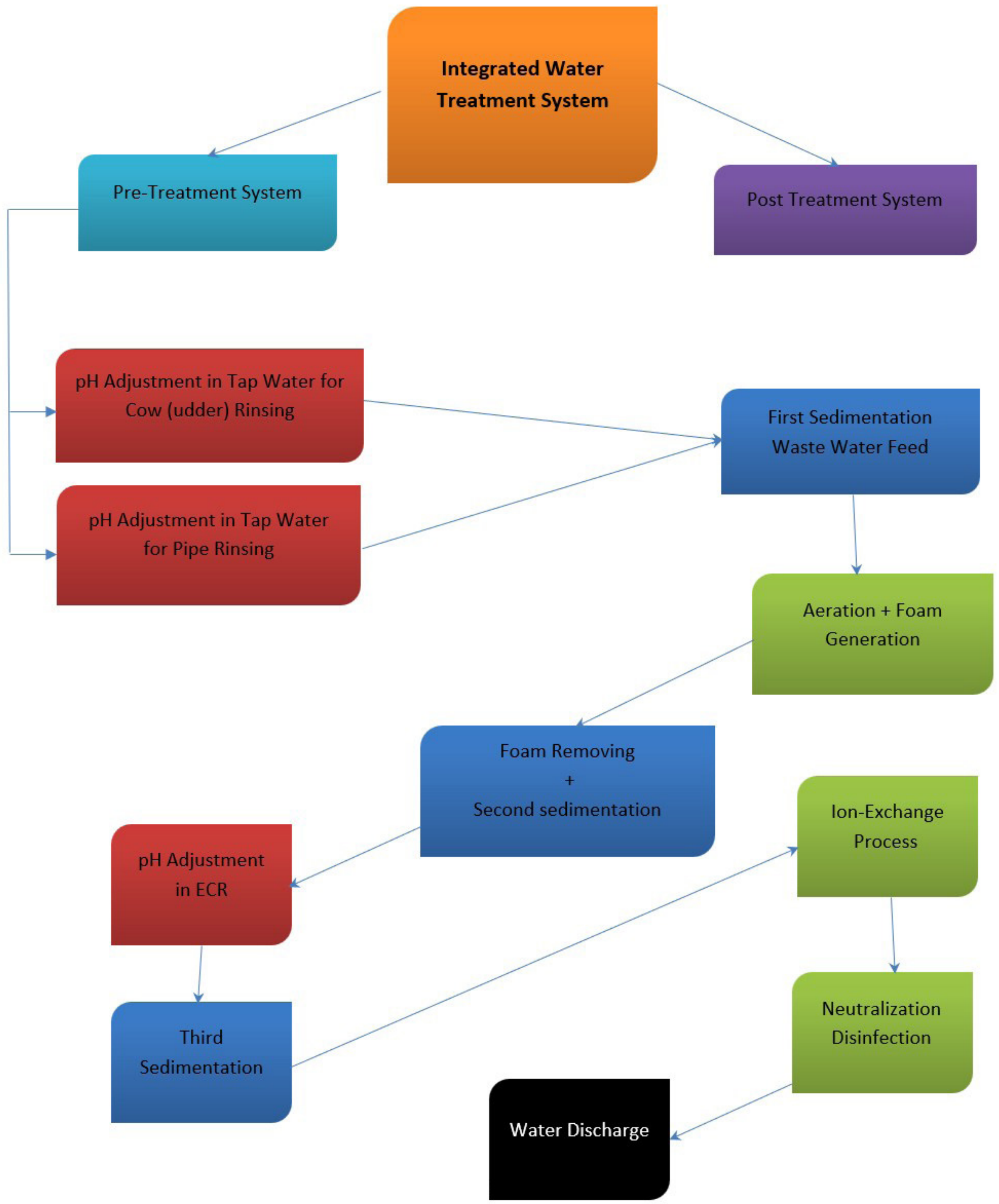
Based on the proposed water treatment methods, preliminary technical studies and patent searches have identified the following subjects for patent applications:

- a complex of modules for advanced treatment of water and aqueous solutions, together with the associated method of use;
- a comprehensive method for water treatment and technological modules for implementing the proposed method;
- a method for the electrolytic extraction of metals from a water or aqueous solution stream, together with electrode cells for implementing the method;
- a method for aerodynamic foaming of water in a continuously flowing stream, together with a foam generator for implementing the method;
- an integrated filtration method combined with ion-exchange treatment and biosorption;
- an electrocoagulation electrode cell with coaxial electrodes;
- an electrocoagulation electrode cell with a continuously moving belt cathode;
- an electrode cell for acidity and alkalinity adjustment incorporating blocks of polarizable soluble electrodes;
- an electrode cell for acidity and alkalinity adjustment utilizing volumetric porous electrodes;
- an electrode cell for acidity and alkalinity adjustment utilizing continuously moving belt electrodes;
- an electrode cell for electrochemical disinfection together with electrode cells for implementing the proposed method.

For each proposed patent application, prototypes and analogous technical solutions have been identified among the developments of Dmytro Lysenko, the author of the proposed new methods. Based on the results of the preliminary patent search and structural analysis, the above technical solutions have been determined to possess full patentability.

Based on the foregoing, it becomes possible, in combination with vertically integrated modularization, to develop a block diagram of an integrated technological complex in which the flexibility and selectivity of each technological process are achieved at the level of each individual module belonging to the lowest level of the hierarchical structure.

Integrated water treatment technology



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AN ARCHITECTURAL MODEL FOR ENSURING FINANCIAL ACCURACY AND CONSISTENCY OF DATA IN DISTRIBUTED OPERATING SYSTEMS

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Abstract

An architectural model for ensuring financial accuracy and consistency in distributed operating systems is proposed. This model addresses the main reasons for discrepancies in financial transactions, such as parallel modifications of records, retransmissions of requests, differences in data formats, and failures of individual components. The architecture requirements include transaction integrity, processing sequence, and traceability of changes, fault tolerance, and information recovery. The main components of the model include a transaction loop, financial journal, event repository, message transmission mechanism, accounting subsystem, analytical subsystem, reconciliation tools, and control tools. Mechanisms such as unique identification of operations, idempotent processing, record versioning, and compensation for previous actions are also considered in this model. It has been found that the combination of these mechanisms can reduce the likelihood of duplicate operations, partial data changes, and conflicts between the components of a distributed system.

Keywords: *financial accuracy, data consistency, distributed system, financial transaction, transaction, event log, idempotent processing, data reconciliation, fault tolerance, data recovery*

Relevance of the study

Modern financial transactions are conducted through information systems that are distributed across various servers, data centers, and software services. These transactions can be reflected in multiple subsystems, including payment, accounting, analysis, and reporting. Therefore, the accuracy and consistency of financial information depend on the reliability of the calculations and data in all parts of the system (Kravchenko D. A., 2022, p. 44).

This issue is of particular significance for financial institutions, as errors, delays in information transmission, reprocessing of transactions, and inconsistencies in record modifications can lead to misrepresentation of information regarding payments, accounts, and liabilities. The requirements for the accuracy, completeness, timeliness, and comparability of data are established in international recommendations for financial risk management and reporting.

A distributed architecture makes it more challenging to maintain a unified data state, particularly in the event of communication failures, component failures, and concurrent processing of operations. Consequently, a model that integrates the mechanisms for transaction processing, synchronization, logging, reconciliation, and data recovery is necessary. Developing such a model would enhance the dependability of financial systems, minimize the risk of mistakes, and generate reliable accounting, managerial, and analytical data.

The purpose of the study

The aim of this research is to create an architectural model that guarantees the accuracy of financial transactions, consistent data modifications, and the maintenance of a single financial state across all components of a distributed system.

Materials and research methods

The research materials included open scientific, regulatory, methodological, and technical sources related to transaction processing, the quality of financial data, transaction logging, and the stability of information systems (Gorbunova A. V., 2025; Kravchenko D. A., 2022; Kuznetsov S. D., Poskonin A. V., 2013; Malyuga K. V., Perl I. A., Slapoguzov A. P., 2021; Popov S. G., Fridman V. S., 2018; Soloviev A. V., 2025; Sukhoplyuev D. I., Nazarov A. N., 2024; Tatarnikova T. M., 2023; Tatarnikova T. M., Shelest M. N., 2022; Fomin D. S., Balsamov A. V., 2021).

Methods such as analysis, generalization of sources, systematization of architectural requirements, and comparative analysis of distributed processing mechanisms were used. Additionally, structural and functional modeling was employed in the work.

The results of the study

Financial accuracy requires accurate representation of monetary values and the absence of errors when performing calculations. To store amounts, you must use precise numeric formats with a fixed number of decimal places. The use of approximate numeric formats can lead to inaccuracies, therefore, the rules for representing monetary amounts, currencies, rounding and bit depth should be the same for all components of the information system (Cowlishaw M. F., Schwarz E. M., Smith R. M., Webb C. F., 2001).

Data consistency at the transaction level means that simultaneous execution of multiple operations should not result in an outcome that would be impossible if the operations were performed sequentially. To achieve this, transaction isolation mechanisms are used to prevent incorrect modifications of interrelated records. In case of a conflict, one of the transactions can be canceled and re-executed. This approach is particularly important when modifying cash balances, limits, liabilities, and other financial indicators.

In a distributed system, it is essential to have a single procedure for recording transactions. Confirmed transactions should be counted in the order they were actually completed, in order to prevent conflicting information from being stored on different nodes of the system at the same time. Therefore, the architecture of a financial system must ensure the consistent confirmation of transactions, the synchronization of data copies, and a unified process for changing the financial status.

The main reasons for the decline in the quality of financial data are fragmented information infrastructure, outdated software solutions and a large number of manual operations. Due to the lack of a unified system for classifying data and information about their origin, it is difficult to combine data, identify errors, and determine when a discrepancy occurred (Kuznetsov S. D., Poskonin A. V., 2013, p. 340).

Inconsistencies can arise from differences in names, identifiers, grouping rules, and how information is presented. If information about accounts, clients, counterparties, or transactions is stored in different systems according to different rules, combining it may result in inaccurate results. To prevent these discrepancies, it is essential to use uniform reference books, identifiers, naming conventions, and automated reconciliation processes.

The architectural model for ensuring financial accuracy and consistency of data should cover all stages of information processing, from the registration of a financial transaction to its reflection in the accounting, settlement, and analytical subsystems. The main requirements for this model are related to computational accuracy, transaction integrity, data uniformity, fault tolerance, and the ability to monitor and restore information (Soloviev A. V., 2025, p. 115). These requirements are presented in (table 1).

Table 1. *Basic requirements for an architectural model to ensure financial accuracy and consistency of data*

Requirement	Content of the requirement
The accuracy of financial calculations	The use of precise numerical types, uniform rounding rules, a set bit depth, and consistent processing order for monetary values in all components of the system
Transaction integrity	Execution of related changes in a single transaction, with confirmation of each operation or cancellation of the entire transaction
Processing sequence	Establishing a unified procedure for recording transactions and implementing transaction isolation mechanisms
Safe re-execution	Repeated processing of cancelled or unconfirmed transactions should not result in repeated write-offs, accruals, or changes to the financial results
Uniformity of data	The use of general reference books, classifiers, formats, names, and identifiers for objects
Traceability of data origin	Storing information about the original source of the information, the steps taken to transform it, and any changes made
Automated reconciliation	Data comparison between operational, accounting, settlement, and analytical systems
Fault tolerance	Maintaining the essential functions of the system in the event of communication failure, increased workload, or failure of individual components
Registration of actions	Maintaining secure logs that contain information about the time, source, action, and result of each event
Protecting information integrity	Restrictions on unauthorized modification of financial data and transaction logs
Backup	Regularly create backups of critical data and verify their ability to be recovered
Crash Recovery	There is a set process for restoring data and verifying its integrity after resuming operations
Responsibility for data quality	Consolidation of data control powers and responsibilities at all stages of data creation, processing, and storage

A source: author's development based on (Kuznetsov S. D., Poskonin A. V., 2013; Soloviev A. V., 2025; Sukhoplyuev D. I., Nazarov A. N., 2024; Fomin D. S., Balsamov A. V., 2021)

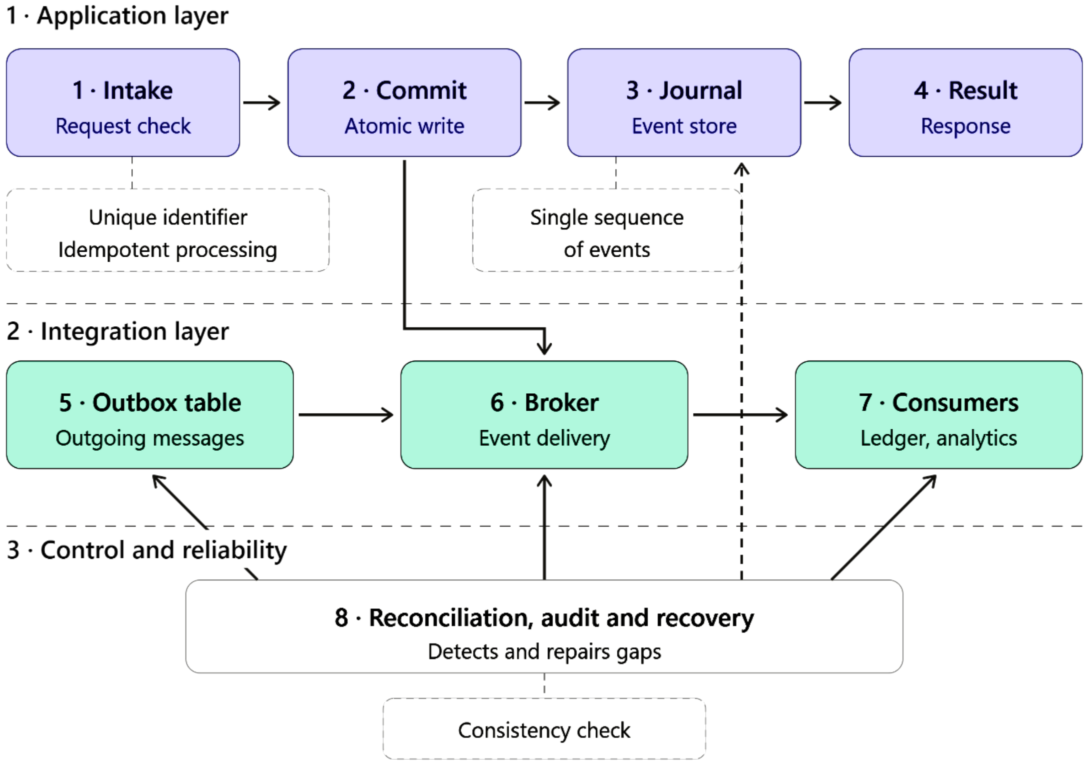
The proposed architectural model revolves around a single framework for recording financial transactions. Initially, the system receives a request and assigns a unique identifier to it. The transaction is then verified and executed in the processing module. The outcome is recorded in a financial ledger, which maintains a consistent record of changes. Simultaneously, information about the approved transaction is added to the outgoing message queue, from where it is transmitted to other system components.

This scheme reduces the gap between changing data and sending information. Based on the outgoing message queuing mechanism, a financial transaction and its corresponding event are stored within a single transaction. If the process is canceled, the message is not sent. However, if the transaction is approved, a separate process passes the event to the message broker (Amazon Web Services).

The financial journal serves as the primary source of information regarding changes made. By storing events in the order they occur, you can restore the state of an object at a specific moment, track the sequence of operations, and generate data for various subsystems. However, derivative representations may not always be updated in real-time, so they should not be relied upon as the sole source of confirmation for a financial transaction.

The model consists of a main transaction loop, financial record log, event transmission, accounting, and analytical representations, as well as a reconciliation module (Figure).

Figure 1. *Architectural model for ensuring financial accuracy and consistency of data (developed by the author)*



To implement the model, various mechanisms are used, each of which handles a specific distributed processing task. (Table 2)

Table 2. *Mechanisms for the implementation of the architectural model*

Mechanism	Appointment
The unique identifier of the operation	Recognizing a repeated request
Idempotent processing	Avoiding repeated data changes during message retransmission
Transactional outgoing message table	Joint recording of financial record and event
Sequential event log	Saving the history and order of changes
Versioning records	Detecting simultaneous changes to a single object
Serializable isolation	Exclusion of results that are impossible with sequential processing

Mechanism	Appointment
Compensating operation	Correction of previously performed actions in case of failure of the next stage
Control reconciliation	Comparison of the operation log and derived representations

A source: author's development based on (Malyuga K. V., Perl I. A., Slapoguzov A. P., 2021; Soloviev A. V., 2025; Fomin D. S., Balsamov A. V., 2021)

The initial conditions for formalizing the model include the equality of interrelated financial records, the absence of repeated changes in the result when processing an operation again, and a consistent sequence of transactions. These conditions are then supplemented by the requirements for accurate representation of monetary values and control verification of the overall journal position.

Each operation must be reflected completely and accurately, with no discrepancies between related records. Repeated receipt of a previously processed request should not result in repeated debit, charge, or balance change. Simultaneous transactions should produce the same result when processed in sequence.

The model also requires that subsystems maintain a causal order of confirmed transactions, which can be brought together in a single financial log. This ensures accurate calculations, eliminates duplicate entries, and allows for a unified financial state of the distributed system.

From a philosophical and methodological point of view, it is incorrect to equate financial accuracy in a distributed system with the equal distribution of all physical copies of data. Due to the fact that the transmission of messages and the creation of analytical representations require limited time, individual subsystems may be at different stages of processing the same data. A more accurate criterion for financial reliability is the preservation of financial invariants within an authoritative transaction cycle, as well as the possibility of comparing each derivative representation with the same confirmed journal entry (Lamport L., 1978; Bailis P., Fekete A., Franklin M. J., Ghodsi A., Hellerstein J. M., Stoica I., 2014; Bação J. L., Guerreiro S., 2026).

With this approach, the financial journal records the operational fact as recognized by the system. Accounting, reporting, and analytical subsystems provide different projections of this fact. However, the formal consistency of records does not necessarily ensure the economic reliability of an original event. An erroneous amount, incorrect invoice, or operation without proper authorization may also be technically consistent with the records. Therefore, it is important to apply mathematical conditions in conjunction with verifying banking details, credentials, and data origin to ensure accuracy and reliability.

Let c denote the currency, o denote the financial transaction, S denote the state of the system, $T(o)$ denote the transformation of the state by operation o, J denote the sequential log of confirmed transactions, and w denote the overall position of the log up to which the processing of the compared data is completed. The notation $\Sigma[X; f(x)]$ further means the sum of the values of $f(x)$ over all $x \in X$.

The first condition is a uniform representation of monetary values. For each currency, a positive monetary quantum $\delta(c) > 0$ and a deterministic rounding rule $R(c,\cdot)$ are established.:

$$M(c, x) = Q(c, x) = \delta(c)\, R(c, x / \delta(c)),\; R(c,\cdot): R \to Z. \quad (1)$$

Here, x is the initial result of the calculation. $M(c, x)$ is the monetary value allowed for recording, and $\delta(c)$ is the minimum accounting unit of the selected accuracy. All components must use the same values of $\delta(c)$, $R(c)$, and the moment when rounding is applied. The monetary quantum does not necessarily coincide with the minimum cash face value of the currency. Higher accuracy may be used for internal calculations. Practical implementation involves storing sums in integer minimum units or an exact decimal format (Cowlishaw M. F., Schwarz E. M., Smith R. M., Webb C. F., 2001).

The second condition is that the balance must be balanced for each transaction and currency. For every transaction, the sum of the debits and credits must be equal:

$$\forall o \in O, \forall c \in C: \Sigma[P(o, c); s(p)m(p)] = =0, s(p) \in \{-1, +1\}. \quad (2)$$

Here, $P(o, c)$ is the set of transactions in the currency *c*, $m(p)$ represents the amount of each transaction in minimum monetary units, and $s(p)$ indicates the side of the record. Different currencies should not offset each other; exchange rate and rounding errors are reflected in separate transactions. Condition (2) is a necessary but not sufficient condition: an erroneous or duplicate transaction can still appear balanced (Ellerman D., 2014).

As a result, for a closed set of accounts N in the same currency c, in the absence of external flows or when the corresponding commission, tax and settlement accounts are included in N, the aggregate invariant $\Sigma[N; b(i, t, c)] = \Sigma[N; b(i, t0, c)]$ holds, where $b(i, t, c)$ – account balance i at time t. This equality is necessary, but not sufficient: mutually compensating errors can save the total amount, therefore, operational control according to formula (2) remains the main one (Ellerman D., 2014).

The third condition is the idempotence of the financial effect. Let s_i^- and s_i^+ denote the states immediately before and after the atomic step of fixing the itch attempt to process the same request with a unique key k and a control value of the normalized content h, and $NPF(S)$ is the financial part of the state. Then

$$|\{i \in \{1,..., n\}: \Pi F(S_i^+) \neq \Pi F(S_i^-)\}| \leq 1. \quad (3)$$

Formula (3) states that any number of attempts to process a request results in no more than one financial change. These repeated attempts may be recorded in the technical journal, as they are not included in the *PF* forecast. To ensure the practical fulfillment of this condition, it is necessary to atomically store the idempotence key and the financial result. Using the same key with k a different value for h should lead to a conflict and should not be interpreted as a repeat of the original operation. This idempotence guarantees a one-time effect, although it does not guarantee that the request will be processed at least once (Akidau T., Balikov A., Bekiroğlu K., Chernyak S., Haberman J., Lax R., McVeety S., Mills D., Nordstrom P., Whittle S., 2013).

The fourth condition involves serializability in competitive execution with regard to financially observable behavior. $ObsF(H, S(0))$ includes the results of financial transactions, response messages, and the final state of history H. For a history containing n confirmed transactions, there must exist a valid sequence of events π.

$$\exists \pi \in Lin(\prec): ObsF(H, S(0)) = ObsF(Seq(\pi), S(0)). \quad (4)$$

Here, $Seq(\pi)$ represents the sequence of transactions $T(\pi(1)), T(\pi(2)), ..., T(\pi(n))$, executed in order from the initial state $S(0)$. The ratio $\prec$ denotes causal precedence, and $Lin(\prec)$ represents a set of linear continuations of this sequence. *ObsF* equality ensures that the financial readings, transactions, balances, liabilities, and final status are all consistent. If strict serializability is used, the order in which non-overlapping transactions occur is also taken into account in the $\prec$ relation. This means that an operation that completes before another operation must come before it in the sequence (Papadimitriou C. H., 1979; Lamport L., 1978; Herlihy M. P., Wing J. M., 1990).

For a strict single-object interface, where $\prec$ includes real-time ordering, this requirement corresponds to linearizability. However, its locality does not guarantee the atomicity of transfers associated with multiple accounts. Such an operation should be considered as a single transaction, and not as a set of independent records (Herlihy M. P., Wing J. M., 1990).

In the case of concurrent transactions, the physical order of completion is not necessarily the same as the order in which they were serialized. The global order of all transactions is not always necessary either. An unambiguous order within a single account, contract, or set of transactions that modify a shared financial invariant is sufficient.

The fifth condition is a reconciliation according to the general position of the financial journal. Let $b(J, w)$ be the remainder vector restored from the log to the position w, $b(r, w)$ be the state of the subsystem r, $Proj(r,\cdot)$ be the rule for constructing its representation, $Obj(r, c)$ be the set of objects to be compared, and $U(J, w)$ and $U(r, w)$ are the sets of identifiers of processed operations in the log and subsystem, respectively. Then

$$D(r, c, w) = \Sigma[Obj(r, c); |Proj(r, b(J, w))(a, c) - b(r, w)(a, c)|] = 0; \quad U(J, w) = U(r, w); \; L(r, w) = t(r, w) - t(J, w) \le \tau(r). \quad (5)$$

The value of $D(r, c, w)$ characterizes the monetary discrepancy. Here, $t(J, w)$ is the time when the position of w was recorded in the log, and $t(r, w)$ is the time the subsystem r reached and provided the state for the same position of w. Therefore, $L(r, w)$ represents the delay in creating the representation, and $\tau(r) > 0$ is its acceptable limit. The use of absolute differences prevents the cancellation of positive and negative errors. Equality of the sets $U(J, w)$ and $U(r, w)$ allows us to identify missing or redundant identifiers. Re-processing is controlled by the uniqueness of the idempotent key.

Comparisons should be made for a single position w. Comparing a current financial journal with a delayed analytical presentation can create a false discrepancy. Formula (5) is the author's reconciliation condition based on the idea of a consistent logical slice of a distributed system (Chandy K. M., Lamport L., 1985).

Conditions (1)–(5) primarily relate to a reliable financial system. In an asynchronous model with the possibility of message loss, it is impossible in all possible scenarios to simultaneously guarantee the linearizability of the read-write object and the execution of each request received by a healthy node (Gilbert, S., Lynch, N., 2002). Thus, in the proposed model, unconfirmed transactions should not be considered committed solely for accessibility reasons. Derived analytical data may still be available and may be temporarily delayed, but they should not be used to confirm financial performance. Their status should be accepted only after agreement in accordance with the common position.

Thus, formulas (1)–(4) define the invariants of financial transaction security, and formula (5) is a verifiable condition for the convergence of derived representations. Financial accuracy in this model does not imply the continuous physical identity of all records, but rather the preservation of a reproducible history, causal relationships, and controlled convergence of data. None of these conditions alone proves the validity of an economic transaction, but their combined implementation allows for the detection of internal contradictions, duplications, disruptions, and incomplete distributions of operations.

The main stages of financial transaction processing are outlined in Table 3.

Table 3. *The main stages of financial transaction processing*

Stage	Content	Result
Accepting the request	Receiving and parsing input data	Generated set of banking details
Checking banking details	Control of required fields and formats	Admission to further processing or refusal
Checking conditions	Control of authority, restrictions, and data availability	Confirmation of the possibility of execution
Transaction execution	Modification of related financial records	Preliminary result of the operation
Completion	Confirming or canceling changes	Fixed or restored state
Status formation	Specifying the result and the reason for the failure if there is an error	Operation status message
Execution control	Checking the completion of processing in all involved components	Confirmation of the final status

A source: author's development based on (Gorbunova A. V., 2025; Tatarnikova T. M., Shelest M. N., 2022; Fomin D. S., Balsamov A. V., 2021)

When implementing the model, it is important to establish the mandatory details of each operation in advance, as well as the rules for verifying them and the acceptable processing states. Verification results should be clear and unambiguous, with reasons for rejection available for analysis. For complex local operations, it may be advisable to use save points that allow for cancellation of only the erroneous part of a transaction. It is also important to determine a procedure in case of component failure, as well as establish recovery indicators.

The recovery time determines the maximum acceptable period of unavailability for a resource, while the backup frequency should consider the goals for recovery time and acceptable data loss. These values are set by the organization based on an analysis of the impact of failures on their activities.

Special attention should be given to testing after making changes to the software, data structure, or the order of processing operations. The Basel Committee emphasizes that issues related to quality and data aggregation must be taken into consideration when developing new products and making modifications to information systems. Additionally, the architecture should ensure the ability to process and prepare data even under conditions of increased workload or crisis situations (Basel Committee on Banking Supervision. 2013).

Continuous monitoring should cover all aspects: computing power, software, work environment, data, unauthorized access attempts, and actions by external service providers. Any detected abnormalities should be analyzed at an early stage, as early detection minimizes possible consequences and reduces the time required for recovery.

Conclusions

The research has shown that achieving financial accuracy in a distributed system requires the coordinated effort of all components involved in the receipt, processing, registration, and transmission of financial data. Our proposed model incorporates transactional processing, event logging in sequence, message transmission, control of execution, and recovery from crashes.

By utilizing unique identifiers, idempotent processing, recording of versions, and reconciliation of records, we can prevent duplicate changes to financial results, detect conflicting transactions, and identify the origins of discrepancies. To ensure the practical implementation of this model, it is essential to establish rules for verifying bank details, monitor the status of operations, test the system after modifications, and continuously monitor its performance. This approach helps reduce the risk of errors and ensures the reliability of the financial condition in the distributed system.

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THE THEORY AND ALGORITHM OF INVENTIVE PROBLEM SOLVING (TRIZ AND ARIZ) (Their Modern Interpretation in the Local Innovation Process of Beachwear Set Design Within a Startup Company)

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Abstract

This publication examines the application of the Theory of Inventive Problem Solving (TRIZ) as a systematic methodology for accelerating innovation within startup companies operating under significant financial, technical, organizational, and professional resource constraints. The article analyzes the relationship between inventive methodology and innate creative abilities, demonstrating that successful innovation can be substantially enhanced through structured engineering approaches based on established principles of technical system evolution.

Drawing upon the pioneering work of Genrich Altshuller and the analysis of more than 40,000 inventor's certificates and patents, the publication explains how recurring patterns of successful inventions led to the development of TRIZ as a practical framework for engineering innovation. Particular attention is given to the transformation of an initial inventive situation into a clearly defined engineering problem by eliminating inefficient solution paths and reducing dependence on trial-and-error approaches.

The article further examines the concept of the Ideal Final Result (IFR) as a fundamental TRIZ principle, emphasizing the achievement of optimal technical solutions through the effective utilization of existing system and environmental resources. The presented methodology provides practical guidance for startup organizations seeking to develop innovative technologies and engineering solutions while minimizing development costs, technical risks, and resource consumption.

Keywords: *Technology Incubator; Innovation Ecosystem; Effective Technology Implementation; Innovative Development Model for Industrial and Agricultural Production; Ecosystem Infrastructure Architecture; Quantum Computing; Augmented Reality Visualization; Testing Laboratories; Laws of Technical System Evolution; Standardization; Technology Transfer*

Introduction

In a typical startup company, resources at the initial stage of development are significantly limited. This applies equally to financial, professional, technical, and organizational resources.

Within the framework of such a startup, is it possible to develop more effective and systematic inventive capabilities by drawing upon the extensive experience accumulated by previous innovators working in similar technological fields under comparable initial conditions? If so, what constitutes this accumulated experience?

What is the actual relationship between inventive methodology – which can be identified, studied, and mastered – and the natural, innate creative abilities of an inventor that cannot be acquired through education alone?

The Soviet patent engineer, inventor, writer, and scientist Genrich Altshuller believed that it was possible to identify consistently recurring patterns underlying successful inventions and to teach these systematic inventive techniques to individuals capable of mastering them. To validate this concept, more than 40,000 inventor's certificates and patents were analyzed. Based on the identified patterns governing the evolution of technical systems and inventive methodologies, the Theory of Inventive Problem Solving (TRIZ) was developed.

When an inventor encounters a technical problem for the first time – particularly during the initial stages of an innovation project – the problem is typically formulated in broad and ambiguous terms and provides no clear indication of an appropriate solution.

Furthermore, startup companies generally possess neither prior manufacturing experience nor production facilities capable of supporting experimental verification of potential solutions.

Within the TRIZ methodology, this initial form of problem formulation is referred to as an **inventive situation**. Its principal disadvantage is that it presents engineers with an excessive number of possible solution paths. Evaluating every alternative is both labor-intensive and costly, while selecting approaches by intuition alone inevitably results in an inefficient trial-and-error process.

Consequently, the first step toward an effective invention is to reformulate the inventive situation in such a way that the problem statement itself eliminates ineffective and unpromising solution paths. This naturally raises an important question: which solutions should be regarded as truly effective?

Genrich Altshuller proposed that the most effective solution is one that is achieved virtually "by itself" through the optimal utilization of resources already available within the system or its surrounding environment. This concept led to the formulation of the Ideal Final Result (IFR), defined as follows:

"An element (the X-element) of the system or its environment independently eliminates the harmful effect while preserving the system's useful function."

In practice, the Ideal Final Result is rarely achieved in its absolute form. Nevertheless, it serves as the fundamental benchmark guiding inventive thinking. The closer a proposed solution approaches the Ideal Final Result, the more effective and elegant that solution is considered to be.

Having established a criterion for eliminating ineffective solutions, the inventor can reformulate the inventive situation into a standard mini-problem within the TRIZ framework:

"According to the Ideal Final Result, the system should remain essentially unchanged; however, either an existing harmful property must disappear or a new beneficial property must emerge."

The primary objective of the mini-problem is to avoid significant – and often costly – modifications to the system while directing inventive efforts toward the simplest, most efficient, and most resource-effective solutions.

The formulation of the **mini-problem** facilitates a more precise definition of the engineering challenge by addressing several fundamental questions:

- What are the components of the system, and how do they interact?
- Which interactions are harmful, obstructive, neutral, or beneficial?
- Which system components and relationships may be modified, and which must remain unchanged?

- Which modifications improve system performance, and which result in deterioration?

These questions provide a sufficient foundation for initiating inventive work. However, during the early stages of an innovation project that is ultimately intended to become a commercially viable product, an additional challenge arises: how can one anticipate the transformation of the invention's most valuable technical characteristics into a set of consumer-oriented properties capable of ensuring not only technological excellence but also commercial success?

To answer this question, let us examine the innovation process step by step.

Once the mini-problem has been formulated and the system has been analyzed, it generally becomes apparent that attempts to improve one system parameter inevitably lead to the deterioration of another. For example, increasing the structural strength of an aircraft wing typically results in greater weight, whereas reducing its weight often decreases structural strength. At this point, a conflict – or contradiction – emerges within the system.

According to the **Theory of Inventive Problem Solving (TRIZ)**, contradictions are classified into three categories, arranged in order of increasing complexity.

Administrative contradiction. This contradiction may be expressed as follows: *"The system must be improved, but I do not know how – or I lack the authority, resources, or capability to implement the required changes."* This represents the least complex form of contradiction and can often be resolved through the acquisition of additional knowledge, organizational changes, or appropriate management decisions. In today's innovation environment, many administrative contradictions arise not only from organizational constraints but also from commercial requirements and market conditions that influence the future implementation and commercialization of an innovative product.

Technical contradiction. This occurs when *improving one parameter of a technical system inevitably causes the deterioration of another parameter*. The technical contradiction constitutes the formal statement of the inventive problem. Reformulating an administrative contradiction into a technical contradiction significantly reduces the complexity of the problem, narrows the search space for possible solutions, and replaces inefficient trial-and-error approaches with the structured methodology of the Algorithm of Inventive Problem Solving (ARIZ). Depending on the complexity of the problem, ARIZ recommends one or more standardized inventive principles or identifies one or more underlying physical contradictions that must ultimately be resolved. In the modern innovation environment, technical contradictions should also be evaluated in light of commercial requirements governing the successful implementation of innovative products.

Physical contradiction. This represents the most fundamental level of contradiction and arises when *a particular component of a system must simultaneously possess two mutually exclusive physical states in order to achieve the desired improvement*. Because such conditions violate the fundamental laws of physics, the inventor must identify alternative physical effects or engineering principles capable of eliminating the contradiction. Classical TRIZ addresses this challenge through the systematic application of physical effects databases and engineering knowledge bases.

This was the traditional approach. What has changed in the modern technological environment?

The emergence of advanced computer modeling technologies, digital engineering platforms, computer-aided design (CAD) systems, simulation software, digital twins, and integrated engineering environments has substantially expanded the repertoire of tools available for inventive problem solving. These technologies enable engineers to evaluate numerous design alternatives rapidly, simulate complex system behavior, predict technical performance before physical prototyping, and significantly reduce the time, cost, and technical risks associated with the innovation process. As a result, modern computational technologies have become an important complement to the classical TRIZ methodology, substantially enhancing both the efficiency and practical applicability of systematic inventive problem solving.

System of Inventive Principles

The analysis of many thousands of inventions has demonstrated that, despite the enormous diversity of technical contradictions, the vast majority can be resolved through the application of 40 fundamental inventive principles.

The development of this system was initiated by Genrich S. Altshuller during the early stages of the Theory of Inventive Problem Solving (TRIZ). Identifying these principles required the systematic analysis of more than 40,000 inventor's certificates and patents, through which recurring patterns of successful inventive solutions were identified.

These inventive principles continue to possess significant heuristic value for engineers and innovators. Their understanding substantially facilitates the search for effective solutions. However, in today's highly competitive commercial environment, their application alone is no longer sufficient to ensure the successful development of innovative products.

The inventive principles primarily indicate the direction in which strong engineering solutions are likely to be found. They do not generate the final solution themselves; the responsibility for selecting and developing the optimal engineering concept remains with the inventor.

The TRIZ system distinguishes between simple inventive principles and paired inventive principles (principle–anti-principle pairs).

Simple inventive principles are primarily intended to resolve technical contradictions, with the forty classical principles representing the most widely applied tools within the TRIZ methodology.

Paired inventive principles consist of a principle and its opposite counterpart and are used to resolve physical contradictions, where mutually exclusive properties, states, or actions must coexist within a technical system.

Standards for Inventive Problem Solving

The Standards for Inventive Problem Solving constitute a structured collection of solution models that employ physical, chemical, or other scientific effects to eliminate contradictions within technical systems. These standards function as generalized engineering solution patterns applicable to broad classes of inventive problems.

To describe the structure of these solution models, Genrich Altshuller developed Substance-Field Analysis (Su-Field Analysis), one of the fundamental analytical tools within TRIZ.

The complete system comprises multiple classes, subclasses, and 76 standardized solution models. Beyond supporting the resolution of inventive problems, the standards also facilitate the identification of previously unrecognized engineering challenges and enable the prediction of future technological evolution.

Technological Effects

A **technological effect** is defined as the transformation of one technological process or engineering action into another. In many cases, technological effects are achieved through the application of underlying physical, chemical, biological, or other scientific phenomena.

Physical Effects

More than 5,000 physical effects and phenomena have been identified within the scientific literature. Different engineering disciplines utilize different groups of physical effects; however, approximately 300 to 500 of these effects are broadly applicable across multiple areas of engineering and technological innovation.

The systematic application of physical effects significantly expands the range of potential engineering solutions and constitutes an essential component of advanced inventive problem solving.

Chemical Effects

Chemical effects represent a specialized category of physical effects in which only the molecular structure of substances is modified, while the governing fields are generally limited to concentration, temperature, reaction rate, and related physicochemical parameters.

Restricting the search for solutions to appropriate chemical effects often enables engineers to identify practical and efficient solutions more rapidly.

Biological Effects

Biological effects are phenomena generated by biological systems, including plants, animals, microorganisms, and other living organisms.

The application of biological effects in engineering not only broadens the capabilities of technical systems but also supports environmentally sustainable innovation by enabling technical solutions that minimize adverse impacts on the natural environment.

Biological effects can be employed to perform a wide variety of engineering functions, including detection, transformation, generation, absorption of matter or energy, environmental adaptation, and numerous other technological operations. Their application has become increasingly important in the development of sustainable, bio-inspired, and next-generation engineering systems.

Mathematical Effects

Among the various categories of scientific effects employed within TRIZ, mathematical effects – particularly geometric effects – have been developed most extensively.

Geometric effects involve the application of geometric forms and relationships to achieve technological transformations. Well-known examples include the engineering use of the triangle, such as wedge mechanisms or systems utilizing two interacting sliding triangular elements. The systematic application of geometric principles frequently enables engineers to simplify technical solutions while improving their functionality and efficiency.

Resources

Substance-Field Resources (Su-Field Resources) are the physical, energetic, informational, spatial, temporal, and functional resources available within or surrounding a technical system that may be utilized during inventive problem solving or system development.

The effective utilization of existing resources increases the **ideality** of a technical system by achieving greater functionality with fewer modifications, lower costs, and reduced resource consumption.

Laws of Technical System Evolution

Through extensive analysis of the historical evolution of technical systems, Genrich Altshuller identified a set of Laws of Technical System Evolution. Knowledge of these laws enables engineers to predict probable directions for future technological development and to design innovations consistent with objective patterns of technological progress.

First presented in Altshuller's book *Creativity as an Exact Science* (Moscow: Soviet Radio, 1979), these laws are traditionally classified into three principal groups.

Statics

The first three laws describe the conditions necessary for the emergence, formation, and initial viability of technical systems.

Kinematics

Laws 4–6 and 9 describe patterns governing system development that are largely independent of specific physical phenomena. These laws are particularly important during the initial growth and maturity stages of technological evolution.

Dynamics

Laws 7 and 8 describe development driven by specific physical factors and become especially significant during the final stages of system evolution, when an existing technical system approaches its developmental limits and transitions toward a fundamentally new generation of technology.

Among all TRIZ principles, the Law of Increasing Ideality is considered the most fundamental. Ideality represents one of the core concepts of TRIZ and serves as the principal criterion guiding technological evolution toward increasingly efficient systems.

Substance-Field (Su-Field) Analysis

Substance-Field Analysis (Su-Field Analysis) is one of the principal analytical methods within TRIZ. A Su-Field model (Substance + Field) represents the minimal functional model describing interactions between system components through a standardized symbolic notation.

Genrich Altshuller developed Su-Field Analysis as a systematic methodology for identifying and utilizing available resources within technical systems. Several TRIZ solution standards employ different combinations of substances and fields to eliminate contradictions while increasing system ideality.

A classical example is the **teletext system**, which utilizes unused intervals within a conventional television broadcast signal to transmit digital information, thereby exploiting existing system resources without introducing additional transmission channels.

Another widely used TRIZ methodology involves the systematic identification and utilization of previously unused substances, fields, and other available resources located either within the technical system itself or in its surrounding environment.

ARIZ – Algorithm of Inventive Problem Solving

The Algorithm of Inventive Problem Solving (ARIZ) represents the most advanced methodological component of TRIZ. It is a structured, step-by-step procedure – consisting of approximately 85 sequential analytical steps – designed to identify, formulate, and systematically resolve contradictions underlying complex inventive problems.

ARIZ integrates three principal components:

- a structured problem-solving algorithm;
- an information support system utilizing the accumulated TRIZ knowledge base and information fund;
- psychological methods designed to overcome cognitive barriers through the **Development of Creative Imagination (DCI)** methodology, an integral component of advanced TRIZ practice.

Various alternative approaches have also been developed to assist inventors in expanding their creative capabilities. Most of these methods are heuristic in nature and are primarily based on principles of psychology and formal logic. Unlike TRIZ, however, none of these approaches claims the status of a comprehensive scientific theory of inventive problem solving.

Alternative Creative Problem-Solving Methods

In addition to TRIZ, a number of established methodologies have been developed to stimulate creative thinking and engineering innovation, including:

- Trial-and-Error Method;
- Brainstorming;
- Synectics;
- Morphological Analysis;
- Focal Objects Method;
- Checklist (Control Questions) Method.

Although these approaches can facilitate idea generation, they are primarily heuristic techniques and generally lack the systematic analytical framework that characterizes TRIZ.

Criticism of TRIZ

Following the death of Genrich Altshuller, the further development of TRIZ slowed considerably. Critics have attributed this stagnation, as well as the practical difficulties associated with applying the methodology, to several factors.

Among the principal criticisms are the following:

- the absence of a universally accepted methodology for solving inventive problems despite numerous attempts to derive one from observed patterns of technological evolution;
- departures from the original dialectical approach through the introduction of concepts regarded by some researchers as inconsistent with the theoretical foundations of TRIZ;
- successive modifications of the Algorithm of Inventive Problem Solving (ARIZ) often increased procedural complexity rather than eliminating previously identified shortcomings;
- the lack of sufficiently effective mechanisms for transforming a formally stated contradiction into a practical engineering solution;
- the continued reliance of many TRIZ tools on extensive exploration of alternative solutions despite the theory's declared objective of minimizing trial-and-error approaches;
- the use within Substance-Field (Su-Field) Analysis of certain theoretical physical fields whose practical applicability has been questioned;
- the difficulty of implementing TRIZ within industrial environments because successful application frequently

depends upon the individual experience, judgment, and creativity of the engineer.

Contemporary TRIZ

Modern TRIZ has evolved into a collection of schools and research directions that continue to develop the classical theory while introducing new concepts not originally included in Altshuller's work.

The core technical components of classical TRIZ – including the **40 Inventive Principles**, **ARIZ**, and **Substance-Field Analysis** – have remained largely unchanged. Consequently, much of the activity within contemporary TRIZ has focused on reinterpretation, restructuring, educational dissemination, and philosophical discussion rather than on significant advances in its engineering methodology.

For this reason, some researchers have criticized modern TRIZ for placing greater emphasis on theoretical interpretation, promotion, and educational activities than on the development of new technical methodologies.

Today, TRIZ is actively applied in fields extending well beyond engineering, including business strategy, marketing, advertising, management, education, the arts, and early childhood development, although it was originally conceived as a methodology for technical creativity and engineering innovation.

Classical TRIZ represents a **general engineering methodology**. However, effective practical implementation increasingly requires the development of specialized TRIZ frameworks tailored to specific industries, each supported by dedicated knowledge bases, information resources, and domain-specific solution models.

Several major international corporations have already developed proprietary adaptations of TRIZ for application within their own technological domains.

In the author's opinion, the same approach should be adopted for startup companies. A specialized version of TRIZ should be developed specifically for startup environments, emphasizing the rapid commercialization of innovations, efficient utilization of limited resources, accelerated product development, and market-oriented engineering decision-making.

At present, no comprehensive specialized versions of TRIZ exist for stimulating scientific discovery in disciplines such as physics, chemistry, biology, and related fields.

One of the principal limitations affecting the continued evolution of TRIZ is the absence of a comprehensive methodology for analyzing initial problem situations, diagnosing emerging technological challenges, and forecasting future innovation opportunities as a basis for defining development objectives within socio-technical systems.

Addressing this limitation has become one of the objectives of the emerging methodology known as Future Design (Futurodesign) – the systematic design of engineering solutions aligned with anticipated technological and societal developments.

Another significant trend influencing technological progress is the growing importance of intellectual property protection. As competition for ownership of innovative technologies intensifies, organizations increasingly require employees capable of generating patentable engineering solutions supported by advanced methodological and software tools.

From this perspective, the TRIZ knowledge base should be expanded to incorporate a broader spectrum of theoretical approaches and modern engineering methodologies.

At the same time, the intellectual successors of Altshuller have generally advocated preserving the original interpretation of classical TRIZ. They are fully entitled to protect the historical identity of the TRIZ methodology and to promote its educational, philosophical, and humanitarian applications.

An alternative approach is to encourage the integration of new methodologies reflecting the technological realities of the twenty-first century while preserving the fundamental scientific value and international recognition of the TRIZ brand.

To avoid unnecessary theoretical disputes, emerging approaches to innovation modeling may ultimately develop under new terminology, particularly since the concepts embodied in the phrase **Theory of Inventive Problem Solving** are broader than the historical framework established during the lifetime of Genrich Altshuller.

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ELECTROMAGNETIC RESONANCE SPECTROSCOPY IN MULTIFUNCTIONAL SENSOR TECHNOLOGY (Potential Applications of Electromagnetic Resonance Spectroscopy within the Infrastructure and Ecosystem of the Smart Pharmacist's Office as a Multifunctional Sensor Technology, Including Medical and Biological Applications, Based on the Innovative Concept Proposed by Specialist Tatiana Gladilina)

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Abstract

This article investigates an experimental technology for the non-contact measurement of the acidity level of liquid biological media intended for application within the infrastructure of a smart pharmacist's office, intelligent pharmaceutical storage systems, and smart manufacturing environments of pharmaceutical production facilities. Particular attention is devoted to the development of an innovative measurement system based on various electromagnetic sensor configurations designed to improve the accuracy, speed, and technological efficiency of acidity monitoring while reducing dependence on conventional contact-based measurement methods.

The study demonstrates that existing standard techniques for acidity determination require mandatory preliminary calibration of measuring equipment using reference buffer solutions, which substantially increases the duration of the measurement procedure and limits the implementation of real-time automated monitoring in intelligent pharmaceutical manufacturing systems. The necessity of developing alternative engineering solutions capable of minimizing calibration-related constraints while improving the operational efficiency of measurement technologies is therefore substantiated.

Particular attention is given to a comprehensive series of experimental investigations performed using distilled water, tap water, and model samples of synthetic gastric fluid with controlled physicochemical properties. Concentrated hydrochloric acid prepared under laboratory conditions was used to modify the acidity of the test samples. Experimental measurements were carried out employing several electromagnetic sensor configurations, including a planar sensor design that demonstrated the highest levels of sensitivity, measurement accuracy, and technological potential.

The analysis of the experimental results, together with an extensive international patent survey, indicates that the application of a planar electromagnetic sensor for the non-contact determination of the acidity of liquid biological media represents a novel engineering solution that has not previously been reported for this class of measurement systems. The obtained results demonstrate the significant potential of the proposed technology for the development of intelligent autonomous devices for continuous acidity monitoring, including miniaturized capsule-based systems intended for monitoring gastric fluid acidity.

Special emphasis is placed on the comprehensive evaluation of the metrological characteristics of the proposed measurement system. The experimental program included investigations of sensor sensitivity to variations in acidity, electrical conductivity, temperature, chemical composition of the test media, and the presence of organic inclusions. In addition, the repeatability of measurement results was evaluated, the obtained data were compared with the readings of conventionally calibrated reference instruments, and the maximum permissible measurement deviations for the monitored parameters were determined.

The obtained results confirm the feasibility and technological potential of employing planar electromagnetic sensors as the foundation of a new generation of intelligent measurement systems intended for digital pharmaceutical technologies, automated quality control of biological fluids, and integration into smart pharmaceutical manufacturing infrastructures. The proposed technology provides a promising basis for the further development of highly accurate non-contact monitoring methods and advanced intelligent medical and pharmaceutical measurement systems.

Keywords: *Pharmaceutical sciences; electromagnetic resonance spectroscopy; sensor technology; Smart Pharmacist's Office infrastructure; Smart Pharmacist's Office ecosystem; critical quality factor; measurement system for key quality parameters of pharmaceutical products following manufacturing and throughout storage prior to use; calibration of measuring instruments using reference buffer solutions with pH values of 4 and 7; calibration procedures performed before pH measurements; autonomous capsule for continuous monitoring of gastric juice acidity in cattle; planar sensor providing optimal integration with adjacent capsule components due to its significantly smaller dimensions while offering higher sensitivity and measurement accuracy*

Introduction

The measurement of the concentration and composition of components in liquid media, in accordance with the methodology and engineering concepts developed and proposed by Tatiana Gladilina, encompasses a broad spectrum of liquid systems, including true solutions, dispersed systems such as emulsions and suspensions, and biological fluids including blood, milk, lymph, urine, and other physiological media. Owing to the high sensitivity of the proposed sensor configurations, the developed technology has significant potential for application in a wide range of scientific, medical, pharmaceutical, and industrial fields.

Potential applications include:

- pharmaceutical manufacturing processes for the production and quality control of medicinal products;
- laboratory and point-of-care analysis of biological fluids, including blood, milk, urine, lymph, and other physiological samples;
- medical, industrial, and food microbiology for monitoring microbial concentrations and detecting the presence of viruses, including coronaviruses.

Electromagnetic Impedance Measurement of Biological Tissues

At present, the measurement of the electrical impedance of biological tissues over a range of alternating-current frequencies is widely employed in clinical diagnostics as well as in biological and medical research.

For example, a significant increase in tissue impedance at low frequencies enables inflammatory processes to be detected at their earliest stages. Certain thyroid disorders can be diagnosed through variations in the phase shift between electric current and voltage.

Electrical impedance mammography has proven to be an effective technique for the early detection of breast cancer. Similarly, measurements of skin impedance facilitate the diagnosis of dermatological disorders, including the identification of amelanotic malignant melanoma, and may also be applied for detecting areas of skin surface contamination by coronaviruses.

Endoscopic impedance measurements can also be employed for the diagnosis of pathological conditions affecting internal organs. Additional applications include non-invasive blood analysis, such as the assessment of elevated blood glucose levels, as well as the evaluation of the physiological condition of lymphatic fluid.

The application of electromagnetic resonance spectroscopy to all of the above-mentioned impedance measurement techniques has the potential to substantially improve measurement sensitivity, selectivity, and diagnostic performance.

Furthermore, the proposed sensor technology may enable the detection of coronaviruses in the human throat during the early stages of infection.

Application of Electromagnetic Resonance Spectroscopy in Biosensor Technologies

The term *biosensor* generally refers to a device in which biological materials – including enzymes, tissues, bacteria, yeast, antigens, antibodies, liposomes, organelles, receptors, DNA, and viruses, including coronaviruses – interact directly with the signal generated by the proposed electromagnetic sensor and produce a resonance response functionally associated with the presence and concentration of the target biological component.

Within the framework of the proposed technology, this approach establishes a fundamentally new method for obtaining information regarding the chemical composition of liquid media.

The presence of biologically active materials possessing highly specific recognition properties enables the selective identification of target compounds within complex multicomponent mixtures without the need for additional analytical procedures involving chemical reagents, biological reagents, sample concentration, or other conventional preparatory operations. Consequently, the proposed approach represents a reagent-free analytical methodology based on electromagnetic resonance spectroscopy, providing a promising platform for next-generation non-contact analytical systems in pharmaceutical, biomedical, and biotechnological applications.

Приложение 1

Potential applications of electromagnetic spectroscopy in multifunctional Sensor Technology in medicine and biology

I. Measurement of the concentration and composition of components in liquids

These include mixtures of both solutions and dispersed systems: emulsions, suspensions, and biological fluids (blood, milk, lymph, urine, etc.). Due to the high sensitivity of the proposed design options for sensors, the proposed technology can be widely used:

1. In the pharmaceutical industry in technological processes for the production of medicines.

2. For laboratory and off-laboratory analyzes of biological fluids: blood, milk, urine, etc.

3. In medical, technical and food microbiology for monitoring the concentration of microorganisms and the presence of viruses, including the corona viruses.

II. Measurement of the electromagnetic impedance of biological tissues of the body Currently, the measurement of the impedance of biological tissues at different frequencies of alternating current is widely used in diagnostics, as well as in biological and medical research. For example, a significant increase in tissue impedance at low frequencies can detect inflammation in the early stages. Some thyroid diseases are diagnosed by a change in the phase angle between current and voltage.

Electro – impedance mammography is an effective method for early diagnosis of breast cancer.

Measuring the impedance of the skin helps to diagnose skin diseases, for example, to detect unpainted malignant melanoma and also to identify foci of contamination of the surface of the skin of the corona viruses. To identify the pathology of the internal organs, an endoscopic impedance measurement can be used. This also includes a non-invasive blood test, for example, for the presence of high sugar levels, and an analysis of the state of lymphatic fluid.

In all the fields of application of impedance measurements listed above, the technology of electromagnetic spectroscopy can contribute, significantly increasing the sensitivity of such measurements.

In addition, the use of these sensors can detect the presence of a corona of viruses in the throat of a person in the initial stages of infection

The use of methods and technologies of electromagnetic spectroscopy in biosensors

The term "biosensor" is usually understood as a device in which biological material: (enzymes, tissues, bacteria, yeast, antigens / antibodies, liposomes, organelles, receptors, DNA, viruses, including corona viruses), directly respond to the presence of a signal from of the proposed sensor and generates a resonant signal functionally associated with the presence and concentration of this component.

In this case, using the proposed device implements a fundamentally new way of obtaining information about the chemical composition of the solution. The presence of a biomaterial with unique properties in the solution allows high selectivity to determine the desired compounds in a complex mixture, without resorting to any additional operations associated with the use of other reagents, concentration, etc. (hence the name – analysis methods without chemical and biological reagents).

Appendix 2. Methodology for Selecting the Operating Frequencies of Resonant Sensors

This methodology describes the initial stage required for the development of a monitoring system intended to determine the concentration of components within a test mixture.

For the purposes of this methodology, a **mixture** is defined as any combination of components in which one component predominates by volume and is regarded as the **reference solvent**, while the remaining components are regarded as **target analytes** (reference dissolved components).

The concept of a *reference solvent* is not limited to a single liquid substance capable of dissolving other materials. It may also comprise a mixture of gaseous, liquid, or even solid substances (for example, a compound material) that serves as the base medium for the formation of solutions, suspensions, aerosols, foams, or other heterogeneous systems.

Accordingly, the target analytes may exist not only in dissolved form but also as suspended particles, bacterial colonies, aerosol droplets, gas bubbles within foams, or filler particles incorporated into composite materials.

Determination of the Optimum Operating Frequency for a Single-Component Monitoring System

Such a monitoring system is intended for technological processes in which the concentration of a single component may vary while the concentrations of all remaining components remain constant.

Preparation of Test Samples

Two samples shall be prepared with concentrations of the target component corresponding to the lower and upper limits of the expected concentration range.

Frequency Scanning

The prepared samples shall be scanned over the entire operating frequency range of the measuring instrument (in the present study, from **0.100 MHz to 170 MHz**).

During the frequency sweep, the measurement system records the variations in both:

- the amplitude of the current passing through the sample; and
- the phase shift between the measured current and the applied harmonic excitation voltage of stabilized constant amplitude.

Analysis of Measurement Results

Following completion of the frequency scan, several frequencies shall be selected at which:

- the difference between the measured current amplitudes of the investigated samples reaches its maximum values; and
- the difference between the corresponding phase shifts reaches its maximum values.

The selected frequencies constitute the initial design parameters for the development and fabrication of prototype resonant sensors.

Selection of the Optimum Sensor

The frequencies identified during the preliminary scanning stage should be regarded only as initial estimates.

To determine the optimum operating frequency for a single-component concentration monitoring system, each prototype resonant sensor shall subsequently be evaluated using at least ten test samples covering the entire anticipated concentration range of the target component, rather than only the two samples employed during the preliminary frequency selection stage. Following experimental evaluation of all prototype sensors, the most suitable sensor may be selected. Preference should be given to sensor designs that exhibit not only high measurement sensitivity but also a monotonic relationship between the measured response and the concentration of the monitored component, thereby facilitating subsequent calibration procedures.

From the standpoint of electromagnetic interference immunity, lower operating frequencies are generally preferable. In addition, practical mechanical and structural design constraints should be taken into account during the final sensor selection process.

Determination of the Optimum Operating Frequencies for a Two-Component Monitoring System

Such a monitoring system is intended for technological processes in which the concentrations of two target components may vary simultaneously, while the concentrations of all remaining mixture components remain unchanged.

Preparation of Test Samples

Two samples shall be prepared for each target component, with concentrations corresponding to the lower and upper limits of their anticipated concentration ranges. In addition, a reference sample shall be prepared in which both target components are completely absent.

These samples provide the experimental basis for determining the operating frequencies that maximize the sensitivity and selectivity of the resonant sensor system with respect to simultaneous variations in the concentrations of the two monitored components.

Frequency Scanning

The prepared samples shall be scanned over the entire operating frequency range of the measuring instrument (in the present study, 0.100 MHz to 170 MHz).

During the frequency sweep, the measuring instrument records the response of each sample by measuring:

- variations in the amplitude of the electric current passing through the sample; and
- variations in the phase shift between the measured current and the applied harmonic excitation voltage of stabilized constant amplitude.

The recorded amplitude and phase characteristics constitute the basis for the subsequent selection of the operating frequencies of the resonant sensors.

Analysis of Measurement Results

For each target component, the frequency scanning results shall be analyzed to identify:

- frequencies at which the differences in the measured current amplitudes between the investigated samples reach their maximum values;
- frequencies at which the differences in the measured phase shifts reach their maximum values; and
- frequencies, or frequency ranges, at which the sensor exhibits sensitivity to one target component while remaining substantially insensitive to the other.

The resulting frequency sets shall then be compared to determine the most appropriate strategy for selecting the operating frequencies of the resonant sensors. Depending on the comparison results, several alternative selection algorithms may be applied.

Case 1. Frequencies Exist That Are Selective to Only One Component

This represents the most favorable scenario for constructing a two-component concentration monitoring system.

If such selective frequencies exist for both target components, the selection of the operating frequencies is straightforward. Prototype resonant sensors should be designed to operate at frequencies where the sensitivity to one component is negligible while the sensitivity to the other component is maximized. At least one operating frequency should be selected for each target component.

If selective frequencies exist for only one of the two components, the operating frequency for that component should be selected where its sensitivity is maximal and the sensitivity to the other component is minimal or absent. For the second component, frequencies should be selected from its candidate frequency set where the difference in sensitivity between the two investigated components is greatest.

Case 2. No Fully Selective Frequencies Exist, but the Frequency Sets Differ

If no frequencies are completely selective for either component, yet the candidate frequency sets identified for the two components do not coincide, prototype resonant sensors should be designed using frequencies that provide the maximum difference in sensitivity between the investigated components.

Case 3. The Candidate Frequency Sets Coincide

This represents the most challenging scenario for developing a two-component concentration monitoring system.

If the candidate frequency sets for both components completely coincide, it is necessary to determine whether the proportional relationship between the amplitude variations or phase-shift variations remains identical at all frequencies.

If this proportional relationship is preserved throughout the entire frequency range, an additional frequency scan should be performed using different excitation voltage levels.

If no differences can be identified following repeated measurements, the investigated components are likely to be indistinguishable by means of electrochemical impedance spectroscopy alone.

Nevertheless, prototype resonant sensors operating at several frequencies corresponding to the highest measurement sensitivity should still be fabricated and experimentally evaluated. Unlike the measuring instrument used during the preliminary scanning stage, a resonant sensor produces a more complex interaction with the investigated sample owing to the additional influence of its resonant electromagnetic field.

If testing demonstrates a change in the proportional sensitivity to concentration variations at even a single operating frequency, the development of a monitoring system capable of discriminating between the investigated components becomes fundamentally feasible. Furthermore, the greater the difference in sensitivity ratios between the components, the higher the selectivity of the resulting monitoring system.

Selection of the Optimum Resonant Sensors

The operating frequencies identified through the preliminary frequency-scanning procedure should be regarded only as initial design parameters.

To determine the optimum operating frequencies for a two-component concentration monitoring system, each prototype resonant sensor shall subsequently be evaluated using at least ten test samples containing different concentrations of the investigated components distributed across their anticipated operating ranges.

Following the experimental evaluation of all prototype sensors, the optimum sensor pair may be selected. Preference should be given to sensors that exhibit not only high sensitivity but also a monotonic relationship between sensor output and the concentrations of the monitored components, thereby facilitating subsequent calibration and quantitative analysis.

Lower operating frequencies are generally preferred because they provide improved immunity to electromagnetic interference.

In addition, practical mechanical, structural, and manufacturing constraints shall also be considered during the final selection of the resonant sensors.

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HIGH-TECHNOLOGY ECOSYSTEM IN THE FOOD INDUSTRY (Stability and Operational Safety of Energy Equipment within the Ecosystems and Infrastructure of Smart Integrated Projects in the Food Industry)

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Abstract

This article examines the operational stability and safety of power-generation equipment operating within the ecosystems and infrastructure of smart integrated projects in the food industry. Particular attention is devoted to the analysis of engineering, computational, and cybersecurity aspects associated with the application of autonomous control systems, onboard computing resources, and intelligent monitoring technologies for power-generation equipment operating under continuously changing technological conditions. The article substantiates the feasibility of implementing adaptive control and computer simulation methods for equipment operating cycles, particularly under the transition from conventional diesel fuel to innovative diesel–methanol fuel mixtures with progressively increasing methanol content. The proposed concept incorporates autonomous software solutions capable of dynamically recalibrating turbine fuel systems, control algorithms, and monitoring parameters without requiring external information carriers. Furthermore, the study considers the integration of high-technology ecosystem principles into intelligent energy infrastructures through the application of innovative information encoding approaches, artificial intelligence, artificial neural networks, non-contact magnetic resonance monitoring technologies, and nanoscale measurement methods. It is concluded that the proposed integrated approach provides a promising technological foundation for improving the operational reliability, safety, and intelligent management of modern energy equipment while supporting the development of next-generation high-technology ecosystems in the food industry.

Keywords: *Energy Equipment; Methanol; Diesel Fuel; Dynamic Fuel Blending; High-Technology Ecosystems; Computer Simulation; Turbines; Equipment Operating Cycle; Turbine Fuel System*

Introduction

Ensuring the operational stability, reliability, and safety of power-generation equipment has become one of the most critical engineering challenges in modern industrial infrastructure. These objectives are increasingly associated not only with conventional control technologies but also with innovative approaches to cybersecurity, intelligent automation, and resilient digital control systems.

In this context, the innovative developments and engineering recommendations proposed by Kateryna Vorobiova provide a valuable technological framework for the successful implementation of next-generation smart technologies within industrial energy systems.

Power-generation equipment employed in industrial and construction projects is typically designed to operate as a highly autonomous system. Consequently, many functions associated with real-time operational control, continuous monitoring, diagnostics, and adaptive process management can be implemented using the computational capabilities of embedded processors and programmable controllers, including the integration of artificial intelligence and artificial neural network technologies.

In many practical applications, computer simulation of equipment operating cycles can likewise be performed using the computational resources available within these embedded control platforms, provided that the simulation tasks are formulated in an efficient and computationally optimized manner.

Major power-generation companies possess substantial engineering expertise aimed at improving electricity generation efficiency through the implementation of advanced fuel technologies. One particularly promising direction is the progressive replacement of conventional diesel fuel with diesel–methanol fuel mixtures, with methanol concentrations increasing to 95–100%.

The introduction of alternative fuel compositions requires the rapid adaptation of monitoring, control, and protection systems, together with the deployment of specialized software capable of accounting for changes in combustion characteristics, operating parameters, calibration procedures, and control-system configurations resulting from modifications to the fuel composition.

Within food manufacturing facilities, there is an increasing demand for protection technologies that can enhance the cybersecurity and operational reliability of monitoring and control systems without introducing significant modifications to existing equipment architecture. Such solutions should preserve the original electrical, mechanical, kinematic, and functional configurations of the equipment while incorporating additional protective components that can be integrated without requiring redesign of the underlying infrastructure.

Industrial operating experience has demonstrated that practical implementation requires compact, autonomous, and computationally efficient protection systems capable of operating independently without relying on external information carriers or additional hardware platforms.

Following an extensive analysis of existing protection technologies, engineering specialists from leading power-generation companies concluded that the most practical and economically efficient solution is the implementation of information-protection systems that require minimal modification of the existing design and control architecture of power-generation equipment.

Leading energy companies applying the technological concepts and engineering recommendations developed by Kateryna Vorobiova within the food industry have become pioneers in the use of methanol as an alternative fuel for industrial gas turbines.

Gas turbines within the 20–25 MW power range traditionally operate using No. 2 diesel fuel as the primary energy source. One of the principal engineering objectives of the proposed technology was to utilize the exceptionally high latent heat of vaporization of methanol, which exceeds that of most conventional liquid fuels and offers significant opportunities for improving combustion characteristics and overall turbine performance.

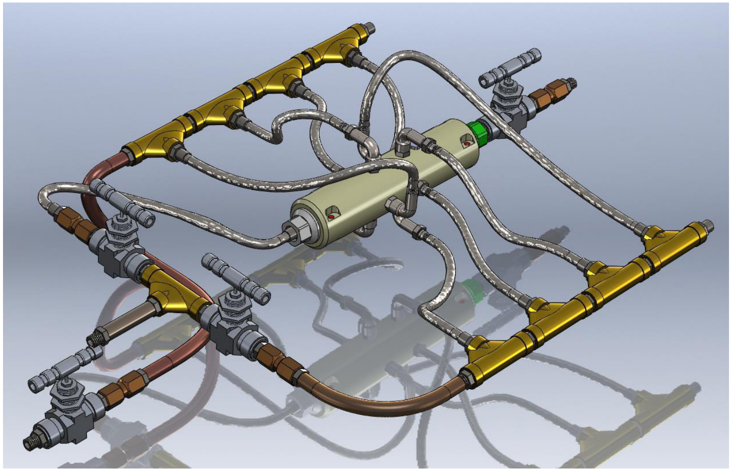
To achieve this objective, several innovative modifications and optimizations of the turbine fuel system were developed. In addition to concepts involving the complete replacement of diesel fuel with methanol, the proposed technology incorporates innovative dynamic fuel-blending systems capable of continuously mixing methanol with controlled proportions of conventional diesel fuel.

Dynamic blending substantially reduces the influence of several unfavorable combustion characteristics of methanol, particularly those associated with its relatively low flame temperature, while preserving the environmental and operational advantages of high-methanol fuel compositions.

Given that hundreds and thousands of industrial turbines currently remain in operation using conventional fuels – including heavy diesel fuel, fuel oil, natural gas, pulverized coal, and other fuel mixtures – it is appropriate to examine the engineering principles governing the adaptation of dynamic methanol blending systems for these various fuel types. Particular attention should therefore be devoted to the comparative analysis of fuel-system modifications and mixing technologies required to ensure the safe, reliable, and efficient operation of modern power-generation equipment under alternative fuel conditions.

The engineering differences associated with adapting dynamic methanol blending technologies to these fuel systems, together with the design and operating principles of the corresponding fuel mixing devices, therefore warrant detailed investigation. During experimental validation and qualification testing, the fundamental engineering concepts of these devices were evaluated under various operating conditions. Although the overall operating principle remained consistent, specific design modifications were introduced depending on the type of fuel employed and the number of fuel components incorporated into the blending process.

Figure 1.



Despite the high degree of standardization and unification achieved in modern fuel preparation and fuel blending systems, the overall performance of thermodynamic energy equipment remains strongly dependent on the mobility, flexibility, and efficiency of monitoring, control, and calibration systems. Particular importance is attached to the capability of these systems to perform real-time adaptation of all incoming and outgoing control signals, thereby ensuring stable equipment operation, reliable process control, and safe integration of alternative fuel technologies under continuously changing operating conditions.

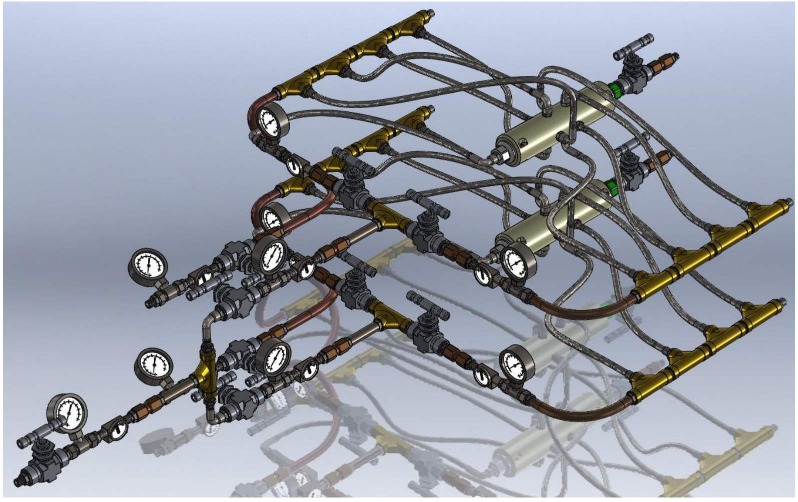
Figure 1 presents a three-dimensional model of a device designed for the dynamic blending of diesel fuel and methanol directly within the fuel supply line of thermodynamic power-generation equipment. The proposed device is characterized by a highly compact and simple design. Even in its basic configuration, it can perform at least two distinct functions: as a static mixer, since the device contains no moving mechanical components, and as an inline static homogenization unit capable of continuously homogenizing fuel or fuel mixtures directly within the fuel supply system.

Owing to the complexity and critical operational requirements of modern power-generation equipment, the integration of even such a compact device requires appropriate recalibration of the equipment's operating characteristics. Consequently, modifications to the software executed by embedded processors and onboard computer systems become necessary in order to accommodate the altered hydraulic, thermodynamic, and control parameters of the fuel system.

From the perspective of mechanical installation and hydraulic integration, the implementation of such modifications represents a routine engineering procedure and generally does not present significant technical difficulties. However, from the standpoint of cybersecurity, the temporary interruption required for software updating, recalibration, or replacement creates a potential vulnerability within the control architecture. During this transition period, malicious software may exploit the communication channel established for software transfer or system reconfiguration to gain unauthorized access to the monitoring and control systems of the thermodynamic equipment.

Considering the inherent inertia and operational complexity of large-scale thermodynamic systems, such unauthorized intrusion may remain undetected for a considerable period. During this interval, cyberattacks may compromise monitoring functions, alter control parameters, or disrupt the operation of critical equipment components before abnormal system behavior becomes apparent to operating personnel.

Figure 2.

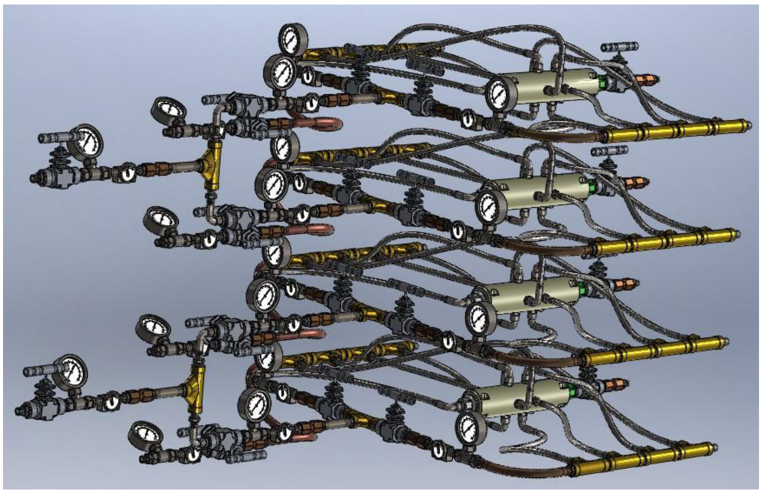


Furthermore, when a dual dynamic fuel blending system is integrated into the equipment, the corresponding cybersecurity risks are effectively multiplied. If the fuel system also incorporates a recirculation circuit for excess fuel, a significantly larger number of components, control modules, and mechanical assemblies may become vulnerable to malicious software, thereby further increasing the technological risks associated with system modernization.

In practical industrial operation, substantially higher volumetric or mass fuel flow rates are frequently required when methanol is introduced as the primary fuel. Compared with conventional diesel fuel, the lower heating value of methanol is approximately half that of diesel fuel. Consequently, achieving an equivalent thermal energy output requires the fuel supply rate to be increased by more than twofold. This requirement substantially complicates the modernization process, since the fuel delivery system must accommodate a significantly greater flow capacity while incorporating approximately twice the number of fuel handling, monitoring, and control devices.

Such a configuration inevitably increases the computational requirements imposed on embedded processors and programmable logic controllers responsible for system management, real-time monitoring, and adaptive control. These additional demands further support the previously discussed conclusions regarding the importance of efficient, autonomous, and cybersecure control architectures for modern thermodynamic energy systems. The following figure illustrates a quadruple dynamic fuel blending configuration comprising four independent mixing units. Depending on operational requirements, each unit may operate either as part of an integrated fuel management system or as an autonomous module, providing enhanced operational flexibility, scalability, and reliability for high-capacity thermodynamic equipment.

Figure 3.



Recent technological developments have led to the emergence of high-capacity dynamic fuel blending systems capable of replacing multi-module configurations while maintaining equivalent or even superior thermodynamic performance. The following figure illustrates one such system with a nominal processing capacity of approximately 1,000 L h^{-1}.

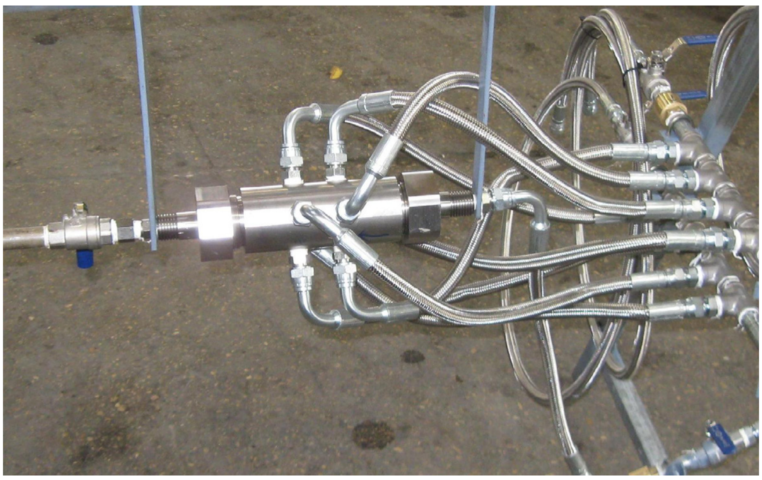
Although this configuration incorporates only three inlet connections and a single outlet, the complexity of its operational control, process monitoring, and hydrodynamic coordination remains comparable to that of larger multi-component systems. Consequently, the computational requirements associated with real-time control, equipment monitoring, and simulation of thermodynamic operating cycles remain equally demanding. The reduction in the number of mechanical components therefore does not diminish the complexity of the underlying control architecture or the computational resources required for reliable operation.

Accordingly, the protection of software loading procedures, firmware updates, and operational deployment of control algorithms into monitoring, analytical, and control systems continues to represent a critical cybersecurity requirement regardless of the configuration or capacity of the fuel blending device employed. Reliable protection of these processes remains essential for ensuring the operational stability, safety, and cybersecurity of modern thermodynamic power-generation equipment.

Based on the engineering requirements identified during the development and practical implementation of such systems, the following fundamental design criteria can be formulated:

- information carriers shall incorporate original built-in system-level protection mechanisms;

Figure 4.



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Based on the engineering requirements identified during the development and practical implementation of such systems, the following fundamental design criteria can be formulated:

- information carriers shall incorporate original built-in system-level protection mechanisms;
- information carriers shall employ identification systems and procedures compatible with those used by processor-based and onboard computer systems;
- the identification code shall be applied to the information carrier without altering the standard geometry or dimensions of its interface and connection elements;
- the identification code shall be based on a single measurable control parameter;
- identification of this parameter shall be performed using a non-contact measurement method.

The above requirements represent only a selection of the principal engineering criteria applicable to secure information carriers. However, currently available portable storage media generally fail to satisfy these requirements in an integrated manner, even when individual protective features are present.

After reviewing the innovative developments and scientific publications of Kateryna Vorobiova in this field, our research group concluded that it was both necessary and promising to evaluate the proposed information carrier encoding methodology in accordance with her concepts and engineering recommendations. As demonstrated in these publications, the proposed technological solutions collectively satisfy not only the engineering requirements outlined above but also a wide range of additional independent and combined technical requirements. Furthermore, they establish a new technological direction based on non-contact magnetic resonance identification, nanoscale measurement technologies, and intelligent data processing incorporating elements of artificial intelligence and artificial neural networks.

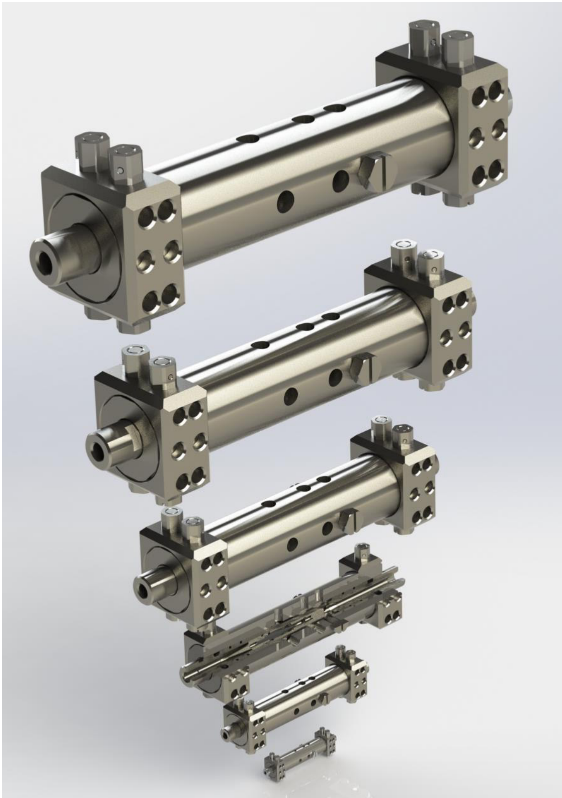
From the standpoint of an engineer specializing in the operation of industrial power-generation equipment, the widespread implementation of this original methodology developed by Kateryna Vorobiova appears particularly promising for manufacturers and operators of specialized computer systems used in power plants and large-scale construction projects. The proposed approach offers the potential to substantially improve the cybersecurity of monitoring and control infrastructures while requiring only minimal modifications to existing hardware configurations.

Because dynamic fuel blending equipment is inherently scalable over a wide range of capacities, the proposed encoding methodology can reasonably be expected to be implemented throughout virtually all sectors of the energy industry. Its application is not limited to industrial gas turbines but may also extend to diesel generators, industrial boilers, combined heat and power plants, and numerous other categories of thermodynamic equipment.

The following figure presents three-dimensional models of dynamic fuel blending devices covering a broad range of dimensional scales. The smallest configurations are suitable for installation in compact industrial or domestic equipment, whereas the largest systems are capable of processing fuel flow rates of several tens of thousands of liters per hour.

The engineering concept proposed by Kateryna Vorobiova significantly expands the possibilities for integrating specialized energy technologies into modern construction and industrial infrastructure projects. Even at the scale of a single power station with an installed capacity of several tens of megawatts, implementation of the proposed methodology has the potential to generate annual economic savings amounting to hundreds of thousands of U.S. dollars while simultaneously providing the highest achievable level of protection for critical monitoring and control systems. Furthermore, within the context of contemporary power engineering, the proposed methodology represents an original and innovative technological direction that combines advanced engineering concepts with novel software solutions. By requiring relatively modest implementation costs, it offers a practical approach to addressing one of the most significant challenges facing modern energy systems – the achievement of a robust and reliable level of cybersecurity for critical industrial control infrastructures.

Figure 5.



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POTENTIAL INNOVATIVE DESIGNS OF MEDICAL EQUIPMENT BASED ON CONTACTLESS MONITORING METHODS (Contactless methods for active online monitoring based on electromagnetic resonance spectroscopy, including applications in liquid media, and prospective innovative medical equipment for the smart physician's office based on these methods)

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Abstract

This article examines innovative contactless methods for monitoring the composition of liquid media as a technological foundation for the development of next-generation medical equipment, particularly intelligent diagnostic systems and real-time monitoring platforms. Special attention is devoted to modern impedance-resonance and electromagnetic resonance technologies, as well as their advanced modifications employing novel engineering materials, composite materials, and carbon-carbon structures subjected to repeated pyrolysis to enhance measurement sensitivity, stability, and analytical performance.

Computer modeling performed by the author demonstrates that these technologies provide the engineering basis for the development of more than ten categories of innovative medical devices. Guided by advanced analytical methodologies, including the Theory of Inventive Problem Solving (TRIZ), the author conducted an extensive patent landscape analysis that resulted in the identification of numerous relevant U.S. patents and patent applications supporting the proposed technological concepts.

Based on comprehensive engineering analysis and systematic computer modeling using the author's proprietary innovation methodology, a series of technical proposals for new medical technologies and innovative engineering projects has been formulated. These concepts integrate advanced contactless monitoring methods with novel materials and composite technologies while providing opportunities for both horizontal and vertical integration with digital technologies, artificial intelligence, and modern computer engineering systems.

The publication also emphasizes that the preliminary engineering evaluation of the proposed devices and medical systems was carried out using professional computer-aided engineering and design software rather than conventional graphical modeling tools, thereby increasing the technical reliability and practical feasibility of the proposed innovation concepts.
Keywords: *Innovative medical equipment; Contactless active online monitoring methods; Innovative medical equipment based on contactless monitoring methods; Contactless active online monitoring based on electromagnetic resonance spectroscopy; Innovative medical equipment for the smart physician's office; Diagnostic systems and online monitoring systems; Real-time contactless monitoring and analytical processing of monitoring results*

Introduction

The following section presents a series of innovative medical engineering concepts based on contactless monitoring technologies and advanced electromagnetic resonance methods. The technological foundation of this project is based on the sensitivity of an electromagnetic resonance sensor to changes in the physical and physicochemical properties of liquid media. The proposed concept is intended to investigate the feasibility of performing a comparative, non-invasive assessment of the general condition of blood without collecting blood samples or penetrating the human circulatory system.

The underlying technological methodology has been developed through experimental studies evaluating changes in water composition produced by the introduction of precisely measured reference substances. During these experiments, the electromagnetic resonance sensor demonstrated the ability to detect microscopic variations in the composition of the liquid medium and to identify corresponding changes in the overall characteristics of the tested mixture.

The proposed sensor is designed as a ring-shaped solenoid into which a patient's finger is placed during the measurement procedure. Prior to examination, the sensor processor is supplied with reference statistical data describing resonance characteristics corresponding to physiologically normal blood parameters while taking into account the individual biological characteristics of the examined person. When the measured sensor response corresponds to the reference resonance profile – including resonance frequency characteristics, signal amplitude, dielectric permittivity, electrical conductivity, and acidity parameters – the system indicates conformity with the reference model by activating a green indicator.

Key distinguishing features of the project

The implementation of this project is intended to result in the development of a medical device suitable for large-scale public use while providing a level of measurement accuracy traditionally associated with sophisticated laboratory diagnostic equipment.

The proposed device has the potential to fundamentally transform the approach to individual health monitoring by enabling rapid, non-invasive assessment of general blood condition, thereby significantly enhancing personal health protection and preventive medical care.

The device is based on an advanced nanometrological technology that has already demonstrated practical applicability in the semiconductor industry. This technological platform has undergone extensive engineering validation, is supported by comprehensive patent protection, and possesses significant licensing and commercialization potential.

Advantages of the proposed technology

The proposed technology establishes a new direction in medical metrology by combining highly sensitive nanoscale sensing with the principles of electromagnetic resonance.

This engineering approach is intended to achieve sensitivity to changes in the overall concentration of blood components at levels approaching **0.000001 milligrams**, while enabling completely contactless and remote monitoring without direct physical interaction with the examined individual.

Because the anticipated manufacturing cost is comparable to that of widely available consumer electronic products, the proposed technology also offers considerable social and public health benefits by making advanced diagnostic monitoring accessible to a broad population.

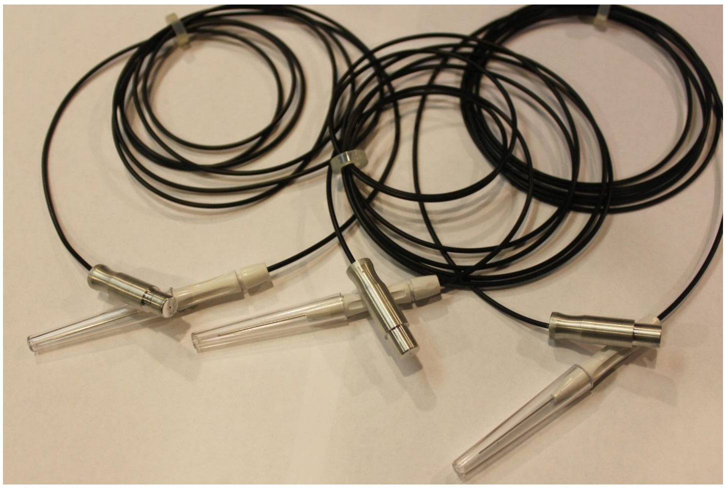
Laser and fiber-optic blood stimulation system for increasing hemoglobin concentration

A complementary project concept involves the development of a laser and fiber-optic system intended to increase hemoglobin concentration through controlled optical stimulation of blood.

The proposed system incorporates electromagnetic resonance monitoring technologies to provide continuous real-time assessment of the overall condition of blood during the treatment process. Such monitoring is intended to prevent exposure beyond established operating parameters that could otherwise result in undesirable or irreversible changes in blood properties.

The integration of continuous resonance-based monitoring with laser and fiber-optic therapeutic technologies is intended to improve procedural safety, optimize treatment parameters, and provide an additional level of control for advanced medical applications.

Figure 1.



The photograph illustrates disposable medical instruments developed on the basis of innovative fiber-optic technologies and protective coding solutions.

The underlying treatment methodology is based on the controlled application of concentrated spectral light within predefined wavelength ranges, frequency characteristics, pulse configurations, and peak optical power parameters designed to achieve the intended therapeutic effect.

Proposed project title

Device with disposable instrumentation for spectral optical blood treatment to increase hemoglobin concentration

Project classification

Research and Experimental Development (R&D) Project

Purpose, objectives, and scope of the project

The objective of this project is to develop a portable medical device based on advanced nanometrological principles and modern spectral-optical technologies capable of providing controlled therapeutic воздействие on blood while simultaneously performing continuous monitoring of its condition throughout the treatment process.

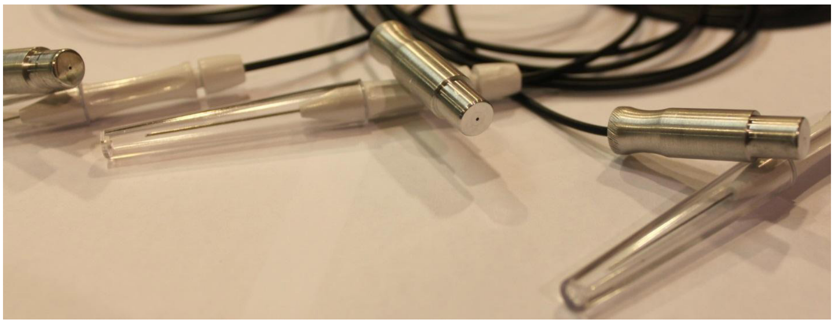
The integration of spectral-optical therapeutic technology with real-time electromagnetic resonance monitoring is intended to provide a stable, controlled, and highly effective process for supporting the restoration of critical blood parameters while maintaining continuous supervision of treatment conditions.

Key distinguishing features of the project

The principal distinguishing characteristics of the proposed project, device, and underlying technology include:

- a simple, reliable, and practical engineering design of both the medical device and its disposable instrumentation;
- the innovative adaptation of advanced technologies originally developed for high-precision semiconductor manufacturing and nanometrology to medical applications;
- the utilization of highly sophisticated optical and fiber-optic engineering solutions to achieve therapeutic effects previously unavailable through conventional medical equipment;
- the integration of disposable optical instrumentation with advanced monitoring technologies, thereby enhancing operational safety, measurement reliability, and clinical usability.

Figure 2.



Advantages of the proposed technology

The proposed technology and the engineering solutions developed for its implementation are characterized by the following advantages:

- utilization of a well-established and experimentally validated technological platform;
- application of technological components and engineering elements that already have counterparts in large-scale industrial production;
- full patentability of both the technology and its individual engineering components;
- simple operation and ease of use, allowing the system to be employed by healthcare professionals without specialized technical training.

Contactless system for non-invasive reduction of subcutaneous adipose tissue

The proposed system incorporates a dedicated operating algorithm specifically designed for controlled contactless treatment of subcutaneous adipose tissue.

Within this concept, electromagnetic resonance technology performs continuous three-dimensional monitoring of the treatment zone, enabling precise localization of the thermal energy applied to the layer of subcutaneous fat most responsive to therapeutic exposure.

The electromagnetic resonance monitoring system also provides continuous measurement and regulation of treatment temperature throughout the procedure, thereby ensuring stable operating conditions and improving process control.

Purpose, objectives, and scope of the project

The project is intended to develop a technology and corresponding medical equipment for the non-invasive reduction of subcutaneous adipose tissue using engineering solutions based on the physical principles of electromagnetic resonance and modern nanometrology.

The primary objective is to create a medical device together with an integrated treatment methodology capable of performing highly localized and precisely controlled processing of subcutaneous adipose tissue without invasive surgical intervention while minimizing undesirable side effects.

The project encompasses comprehensive scientific research followed by engineering development and prototype implementation based on the obtained research results.

Key distinguishing features of the project

The principal innovation of the proposed project lies in the application of electromagnetic resonance nanometrology for highly precise, localized, actively controlled, and continuously monitored thermal treatment of subcutaneous adipose tissue.

Advantages of the proposed technology

The principal advantage of the proposed technology is its ability to maintain continuous control over all critical treatment parameters. Such precision is intended to achieve effective localized processing while avoiding thermal injury or damage to adjacent untreated tissues, thereby maximizing procedural safety and treatment accuracy.

Electromagnetic resonance system for the early detection of malignant neoplasms

The proposed system has been developed in several engineering configurations.

The most innovative concept is based on specially designed patient-specific examination garments manufactured from electrically conductive carbon-carbon composite fabric. Owing to the unique structure of the woven material, the textile itself functions as either a planar or three-dimensional solenoid, enabling contactless electromagnetic resonance measurements.

The examination procedure is performed by dividing the patient's body surface into multiple monitoring zones. The reflected resonance signal obtained from each zone is compared with a statistical reference signal corresponding to a clinically healthy individual with the same body dimensions and garment size.

The carbon-carbon composite material is suitable for repeated sterilization using conventional autoclave procedures and may also be sterilized using microwave technology.

A second system configuration is intended for localized examinations and incorporates a sensor assembly geometrically adapted to the anatomical region corresponding to the organ under investigation.

Comparison of the resonance signal obtained from the examined organ with the corresponding reference signal from healthy tissue provides the basis for identifying changes that may warrant further clinical investigation.

Purpose, objectives, and scope of the project

The objective of this project is to develop a technology and medical device intended to investigate the feasibility of extremely early detection of malignant neoplasms using contactless electromagnetic resonance monitoring. The project aims to develop a medical system based on advanced contactless nanometrological and electromagnetic resonance technologies with a projected analytical sensitivity capable of detecting structural changes on the order of approximately 100 angstroms and mass variations approaching 0.000001 milligrams.

Such analytical sensitivity is intended to support the identification of pathological changes at their earliest stages, thereby creating opportunities for timely clinical assessment and medical intervention before irreversible disease progression occurs.

Key distinguishing features of the project

The proposed project is characterized by fundamentally novel primary and auxiliary engineering solutions.

The technical concepts underlying the proposed technology are fully patentable and are presented as original engineering developments. The proposed system is designed using components and materials already available through industrial manufacturing, thereby eliminating the need for developing specialized production technologies.

Advantages of the proposed technology

The principal advantage of the proposed technology is its exceptionally high analytical sensitivity, which constitutes the foundation of its projected diagnostic capabilities.

Electromagnetic resonance system for the early detection of reduced calcium concentration in bone tissue

This project is based on a sensor garment concept similar to that proposed for the early detection of malignant neoplasms. The principal distinction is that the statistical reference database consists of analytical measurements corresponding to bone tissue with physiologically normal calcium concentration.

Research and Experimental Development (R&D) Project

Purpose, objectives, and scope of the project

The project is intended to investigate the scientific principles underlying the preventive assessment of changes in calcium concentration within bone tissue and to develop a corresponding contactless diagnostic technology.

The primary objective is to create a universal medical device capable of detecting variations in calcium concentration with a projected analytical sensitivity approaching 0.000001 milligrams.

Key distinguishing features of the project

The principal innovation of the proposed system lies in the application of electromagnetic resonance nanometrology for the contactless detection and assessment of changes in calcium concentration throughout bone tissue.

Advantages of the proposed technology

The proposed technology and its implementation methodology offer significant advantages over existing approaches. These advantages include high analytical accuracy and sensitivity, enabling the detection of even minimal deviations during routine outpatient examinations at a stage when corrective or therapeutic intervention remains both feasible and clinically effective.

Real-time electromagnetic resonance system for monitoring bone fracture healing

The proposed system is based on a flexible and elastic solenoid fabricated from electrically conductive carbon-carbon composite fabric produced through the pyrolysis of viscose textile substrates. The textile solenoid is configured as a localized bandage positioned over the fracture site and continuously connected to a processor containing statistical reference data representing the electromagnetic resonance characteristics of healthy bone tissue.

Purpose, objectives, and scope of the project

The purpose of this project is to conduct scientific research and engineering development leading to the creation of a technology and equipment for real-time therapeutic monitoring capable of supporting clinical decision-making throughout the active phases of treatment and rehabilitation.

The principal innovative characteristics of the proposed project include:

- application of electromagnetic resonance principles to identify structural changes in bone tissue within the fracture zone;
- completely contactless monitoring without any direct physical interaction during examination;
- capability for continuous remote monitoring of the patient's condition;
- high analytical accuracy and measurement sensitivity;
- reliable identification and interpretation of monitoring results through integrated signal analysis.

Advantages of the proposed technology

The proposed technology combines high measurement accuracy and analytical sensitivity with continuous remote transmission and interpretation of monitoring data. This enables timely clinical decision-making in real time and has the potential to improve the effectiveness of treatment and rehabilitation.

Electromagnetic resonance system for the therapeutic destruction of cholesterol plaques in arteries

The proposed project investigates the development of an electromagnetic resonance therapeutic system intended for the targeted treatment of cholesterol plaques within arterial vessels through controlled resonance-based energy delivery while providing continuous monitoring of treatment parameters.

Electromagnetic resonance system for the detection and non-invasive treatment of arterial cholesterol plaques

The proposed system is based on the capability of electromagnetic resonance technology to distinguish between muscular tissue and liquid media. By continuously comparing resonance signals, the system is intended to identify with high precision the boundary between soft tissue and blood, corresponding to the arterial wall.

Following localization of the treatment area, controlled thermal energy is directed toward regions of the arterial wall containing cholesterol plaque deposits. The treatment process is designed to maintain precise temperature control and three-dimensional spatial localization of the thermal exposure. Under controlled thermal conditions, the plaque material is intended to undergo gradual structural degradation, after which the resulting products are expected to be eliminated through the body's natural biological metabolic processes.

The proposed therapeutic methodology is conceived as a preventive treatment strategy in which periodic procedures are performed to reduce or limit the progressive accumulation of cholesterol deposits within arterial vessels.

From an engineering perspective, the system consists of electromagnetic resonance sensor modules mechanically integrated with pulsed thermal energy generators through a flexible positioning and adjustment mechanism.

The same structural platform and electromagnetic resonance localization technology may also support other forms of therapeutic energy delivery depending on the intended clinical application, including radiological and laser-based methods for superficial treatment.

Purpose, objectives, and scope of the project

The project is intended to investigate and develop technologies and medical equipment for the non-invasive detection and treatment of cholesterol plaques within arterial vessels.

The primary objective is to conduct comprehensive scientific research and experimental investigations that will establish the scientific and engineering foundation necessary for the subsequent development, prototyping, and evaluation of the proposed system together with its intended clinical methodology.

Key distinguishing features of the project

The principal innovation of the project lies in the integration of electromagnetic resonance technology with precisely controlled inductive thermal treatment for the identification, localized disruption, and subsequent biological elimination of cholesterol plaques and their degradation products.

Advantages of the proposed technology

The proposed technology is characterized by the high analytical accuracy and sensitivity of its electromagnetic resonance sensor modules. These capabilities are intended to support the detection of cholesterol plaque formation at its earliest stages and to facilitate therapeutic intervention while the deposits remain comparatively small and more readily managed through non-invasive treatment.

Electromagnetic resonance scanning system for preventive assessment of skeletal muscle condition

The proposed system consists of an electromagnetic resonance scanning module designed to move across the body surface during examination. The system incorporates at least two sensor elements whose magnetic field vectors intersect, creating a controllable three-dimensional sensing volume. The geometry of this intersection can be adjusted according to the specific diagnostic objectives of the examination.

An additional reference sensor continuously determines and controls the effective depth of investigation.

The fundamental physical principles governing the operation of the system remain the same as those described for the preceding applications. Consequently, they are not repeated for each individual implementation of the proposed technology.

Purpose, objectives, and scope of the project

The purpose of this project is to conduct fundamental scientific research leading to the development of the initial engineering requirements for subsequent prototype design and experimental development.

The primary objective is to prepare the complete engineering documentation, manufacture a functional prototype, and perform a comprehensive program of preliminary technical testing.

The project is intended to produce a prototype medical device capable of performing preventive assessment of skeletal muscle condition using technological principles based on electromagnetic resonance.

Key distinguishing features of the project

The proposed project is characterized by the following innovative features:

- assessment of skeletal muscle condition through identification and interpretation of electromagnetic resonance sensor signals;
- acquisition of integrated reflected resonance signals representing the overall structural and functional condition of muscle tissue, including its physiological activity.

Advantages of the proposed technology

The proposed technology enables completely contactless layer-by-layer assessment of skeletal muscle tissue while generating a three-dimensional representation of its overall condition.

Electromagnetic resonance system for preventive detection of bronchial and pulmonary secretions

The proposed system consists of a sensor array together with positioning mechanisms that accurately orient the sensors during examination.

Its operating principle is based on comparative analysis of resonance signals obtained from clinically healthy individuals and corresponding signals acquired from the examined patient.

The sensor assembly incorporates a central processor together with a dedicated analytical coprocessor. The software required for signal processing and comparative analysis is intended to be developed as part of the project.

The system is designed to detect deviations from established reference resonance characteristics. The magnitude of these deviations is intended to provide an indirect indication of the presence and relative extent of bronchial or pulmonary secretions.

The proposed technology is conceived as a preventive diagnostic tool that may reduce the need for certain conventional radiographic examinations in selected clinical applications.

Purpose, objectives, and scope of the project

The objective of the project is to develop an efficient diagnostic device together with its associated technology and methodology for improving preventive medical examinations and supporting the earlier detection of respiratory disorders.

The proposed application of electromagnetic resonance phenomena for preventive diagnostic assessment represents an original engineering concept requiring comprehensive scientific investigation.

Key distinguishing features of the project

The proposed technology is characterized by:

- high analytical accuracy and diagnostic performance;
- broad potential applicability within preventive and clinical medical practice;
- relatively low equipment and operating costs;
- significant potential public health benefits through earlier identification of disease processes.

Advantages of the proposed technology

The principal advantages of the proposed technology include:

- completely non-invasive operation without known harmful effects during or after examination;
- simple operating procedures requiring minimal user training;

- favorable cost-effectiveness relative to the anticipated diagnostic capabilities;
- the potential to substantially improve the effectiveness of preventive diagnostic screening.

Electromagnetic resonance system for preventive monitoring of arterial blood flow velocity

The proposed system employs flexible sensor solenoids manufactured from electrically conductive carbon-carbon textile composites. These sensors are positioned at selected anatomical monitoring points or localized regions of the patient's body. During examination, the flexible sensor assemblies conform closely to the skin surface, allowing resonance signals to be acquired and analyzed for the assessment of arterial blood flow velocity. The proposed methodology is based on comparison of measured parameters with statistically established reference values representing normal blood flow characteristics.

Purpose, objectives, and scope of the project

The objective of this project is to develop a contactless medical device for the preventive assessment of the vascular system without the need for any invasive procedures.

The project encompasses a complete cycle of scientific research and experimental development activities leading to the design, construction, and validation of the proposed medical device.

The fundamental inventions underlying the project represent original engineering solutions that are intended to provide an exceptionally high level of measurement accuracy and analytical capability.

Key distinguishing features of the project

The principal innovation of the project lies in the practical implementation of electromagnetic resonance sensing for the measurement and identification of physiological parameters using engineering principles that represent an original technological concept.

All measurements are performed entirely without physical contact and are intended to operate without direct mechanical interaction with the patient's body.

Advantages of the proposed technology

The primary advantages of the proposed technology include its engineering simplicity, comparatively low production cost, and the combination of high measurement accuracy with advanced analytical interpretation of acquired data.

Electromagnetic resonance system for restorative stimulation of muscle tissue

The proposed system is intended to provide contactless electromagnetic resonance stimulation of skeletal muscle and soft tissues to support the restoration of their functional activity. The technology may be used either independently or in combination with thermal contrast therapy devices, as well as localized heating or cooling systems. By combining multiple electromagnetic resonance excitation modules operating at different functional levels with a high-precision resonance positioning system capable of controlling the depth of treatment with sub-millimeter accuracy, the proposed technology enables layer-by-layer electromagnetic resonance treatment of muscle tissue, either as a standalone therapy or together with contrast thermal treatment. For patients affected by arthritis and related musculoskeletal disorders, the proposed approach is intended to provide precisely localized therapeutic stimulation of affected tissues. The system also enables contrast therapy to be applied selectively within specifically identified pathological regions, thereby improving treatment precision and control.

Proposed project title

Device with instrumentation and contactless therapeutic modules for comprehensive electromagnetic resonance stimulation of muscle tissues, including internal organs, to support the restoration of their functional activity.

Purpose, objectives, and scope of the project

The project is intended to develop, on the basis of advanced nanotechnology and electromagnetic resonance engineering, a medical device capable of supporting restorative therapeutic procedures in outpatient settings without dependence on specialized medical facilities. The proposed technology is based on established physical principles of electromagnetic resonance and incorporates a family of patented engineering solutions protecting both the structural configuration and technological concepts of the proposed system. The project includes a complete cycle of scientific research, engineering development, prototype construction, and experimental evaluation.

Key distinguishing features of the project

The principal distinguishing characteristics of the proposed technology include:

- completely contactless operation during all treatment procedures;
- application of the precision and analytical capabilities of electromagnetic resonance technologies;
- utilization of unique naturally occurring engineering materials within the device architecture;
- development of equipment suitable for routine outpatient medical practice.

Advantages of the proposed technology

The proposed technology is intended to provide exceptionally high spatial precision in identifying treatment locations and maintaining accurate positioning throughout therapeutic procedures. This high level of precision is expected to enhance the effectiveness of restorative and preventive treatment by enabling accurately controlled therapeutic intervention.

Conclusion

The concepts presented in this publication represent only a portion of the potential applications of electromagnetic resonance monitoring technologies. Numerous additional developments may be realized in the field of continuous real-time patient monitoring using contactless electromagnetic resonance sensors designed to operate without harmful effects or undesirable physiological consequences. For such applications, the author proposes the use of flexible composite solenoid structures that function not only as sensing elements but also as medical dressings. Because these structures are manufactured from carbon-graphite composite fabrics, disposable versions may simultaneously perform diagnostic monitoring and serve as sorptive wound dressings, thereby providing additional therapeutic benefits while supporting continuous physiological monitoring.

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THE GLOBAL ARTIFICIAL INTELLIGENCE INDUSTRY: ENERGY CHALLENGES (The Global Artificial Intelligence Industry: Emerging Challenges, Threats to Energy Infrastructure, and Potential Solutions)

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Abstract

This publication examines an emerging challenge facing the global artificial intelligence industry, where the primary constraint is no longer software development or the availability of advanced semiconductor chips, but the growing limitations of energy infrastructure. As artificial intelligence technologies continue to expand, the increasing demand for computational capacity has resulted in the rapid construction of large-scale data centers, placing unprecedented pressure on existing electrical power systems.

The study analyzes the relationship between the accelerated growth of artificial intelligence applications and the continuously increasing electricity consumption of modern data centers. It demonstrates that, in many regions, electrical grid capacity is approaching its operational limits, creating significant challenges for the further expansion of AI infrastructure and the deployment of next-generation computing facilities.

Particular attention is devoted to the conventional backup power solutions currently employed by data centers. For many years, industrial diesel generators have represented the standard technology for ensuring uninterrupted power supply during grid outages. However, these systems are becoming the subject of increasing environmental, regulatory, and public criticism. The publication highlights the example of the U.S. state of Virginia, widely recognized as the world's largest concentration of data centers, where more than 10,500 diesel generators are currently connected to data storage and processing facilities. Their extensive deployment has generated growing public concern and intensified regulatory pressure regarding environmental emissions and infrastructure sustainability.

Keywords: *Artificial intelligence industry; Energy infrastructure; Software; Emerging challenge; Technology companies and data centers; Backup power solutions; Industrial diesel generators; Integration with data storage and processing facilities; Alternative backup power supply system based on Aluminum-Air technology; Electrochemical reaction between aluminum plates and oxygen from ambient air; Such participation has highlighted*

the growing interest of technology giants in next-generation energy solutions; Global backup power market for data centers; Metal-air battery technology; The oxygen cathode consists of a hollow air-filled structure that allows oxygen to circulate freely within the battery

Against this background, considerable attention has been drawn to Phinergy, a company developing alternative energy technologies. At the Datacloud Global Congress held in Cannes, the company presented an alternative backup power supply system based on Aluminum-Air technology.

The company's Chief Executive Officer shared the stage with executives from Google and Microsoft, highlighting the growing interest of leading technology companies in next-generation energy solutions for critical infrastructure.

The Phinergy system generates electricity through an electrochemical reaction between aluminum plates and oxygen extracted from the ambient air. According to the company's Chief Executive Officer, the market requires a backup power solution capable of providing the same level of reliability and rapid start-up as conventional diesel generator systems, while eliminating their environmental impact.

Figure 1.

A key feature of the proposed technology is the absence of self-discharge. During standby operation, the liquid electrolyte is stored separately, while the aluminum elements remain dry. In the event of an emergency power outage, the electrolyte is automatically supplied to the system, initiating the electrochemical reaction and enabling immediate power generation.

A single power module is capable of providing uninterrupted electrical power for up to 48 hours. If the emergency extends beyond this period, the aluminum plates can be replaced without interrupting the operation of the equipment, thereby ensuring continuous power supply.

Introduction

Last year, Phinergy's solution was selected as one of the winners of the Net Zero Innovation Hub program. The consortium is led by Google and Microsoft in cooperation with Danfoss, Data4, Vertiv, and Schneider Electric. The proposal was selected from more than 70 competing projects submitted by participants from around the world.

The company is currently implementing a funded pilot project with a rated capacity of 500 kW and an energy storage capacity of 10 MWh at a demonstration site selected by the program participants.

According to industry experts, the global market for backup power systems for data centers is expected to reach USD150–200 billion within the next five years. Against this backdrop, Phinergy has already signed a preliminary agreement with one of the world's largest cloud service providers regarding the potential deployment of backup power systems with an aggregate capacity on the gigawatt scale by 2030.

The technology has already entered practical application. In Switzerland, the company cooperates with Swisscom Broadcast. In Israel, the deployment of backup power systems at 300 major road intersections began in April in cooperation with Netivei Israel. The solution enables critical infrastructure to remain operational for three to four days in the event of a power outage.

According to published reports, during the attack of October 7, backup power systems developed by Phinergy were automatically activated at mobile communication facilities located near the border with the Gaza Strip, helping to maintain the operation of the cellular communication network during the initial hours of the emergency.

Aluminum-Air backup power systems represent an environmentally sustainable electricity generation technology that produces electrical energy through the electrochemical reaction of aluminum, atmospheric oxygen, and water or an alkaline electrolyte. These systems operate as high-energy electrochemical power sources, providing high energy density together with extended autonomous operating time.

Operating Principle

Energy carrier. Replaceable metallic aluminum anodes serve as the primary energy source.

Oxidation process. Aluminum reacts electrochemically with atmospheric oxygen and an aqueous solution or alkaline electrolyte.

Electricity generation. The electrochemical reaction releases electrons, producing electrical current together with heat and hydrogen.

Environmentally safe by-product. The reaction produces aluminum hydroxide as its final product. This environmentally safe material can be collected and recycled into pure aluminum, thereby supporting a circular materials cycle.

Principal Advantages

- Zero self-discharge. During standby operation, the electrolyte and aluminum plates are stored separately, allowing the system to remain fully operational for many years without energy loss;
- High specific energy density. The technology provides substantially higher energy density than conventional lithium-ion and lead-acid batteries of comparable weight and volume;
- Zero local emissions. The system produces no harmful exhaust emissions at the point of use, unlike conventional diesel generators;
- Extended autonomous operation. The technology is particularly suitable for multi-day backup power applications.

Technological Limitations

- Fuel replacement requirement. As the aluminum plates are gradually consumed during operation, they must be physically replaced;
- Management of reaction by-products. Conventional systems required complex electrolyte purification; however, modern technological developments, including those introduced by Phinergy, address this challenge through closed-loop processing;
- Infrastructure requirements. While certain compact aluminum-air generators may be activated using either fresh water or seawater, stationary megawatt-scale installations require dedicated servicing and operational infrastructure.

Application Areas in 2026

The principal application areas for aluminum-air backup power systems include:

- Industrial facilities and data centers. Major technology companies, including Microsoft and Google, in cooperation with Phinergy, are evaluating aluminum-air technology as an environmentally sustainable alternative to conventional diesel backup generators;
- Autonomous residential buildings and microgrids. The technology provides reliable backup power for several days without noise, vibration, or harmful emissions;
- Portable emergency generators. Compact generators with output capacities ranging from 500 to 1,000 W can be activated using only water, making

them suitable for emergency and field applications.

The Future of Energy Storage: Metal-Air Batteries

Rechargeable batteries are currently used across a broad spectrum of technologies, including mobile devices, electric vehicles, renewable energy systems, and numerous industrial applications. However, existing battery technologies remain constrained by limitations in energy density and overall efficiency.

In recent years, metal-air batteries have attracted considerable research interest as one of the most promising approaches for substantially increasing energy density while improving the overall efficiency of electrochemical energy storage systems.

This article examines the design, operating principles, principal types, advantages, and limitations of metal-air batteries, together with their prospective applications in future energy systems.

Design and Operating Principle of Metal-Air Batteries

Metal-air batteries (Metal-Air Batteries) are a class of electrochemical energy storage devices in which electrical energy is generated through the oxidation of a metallic electrode using oxygen from the ambient air.

These batteries are characterized by exceptionally high energy density, enabling them to provide significantly greater energy storage capacity than many conventional battery technologies.

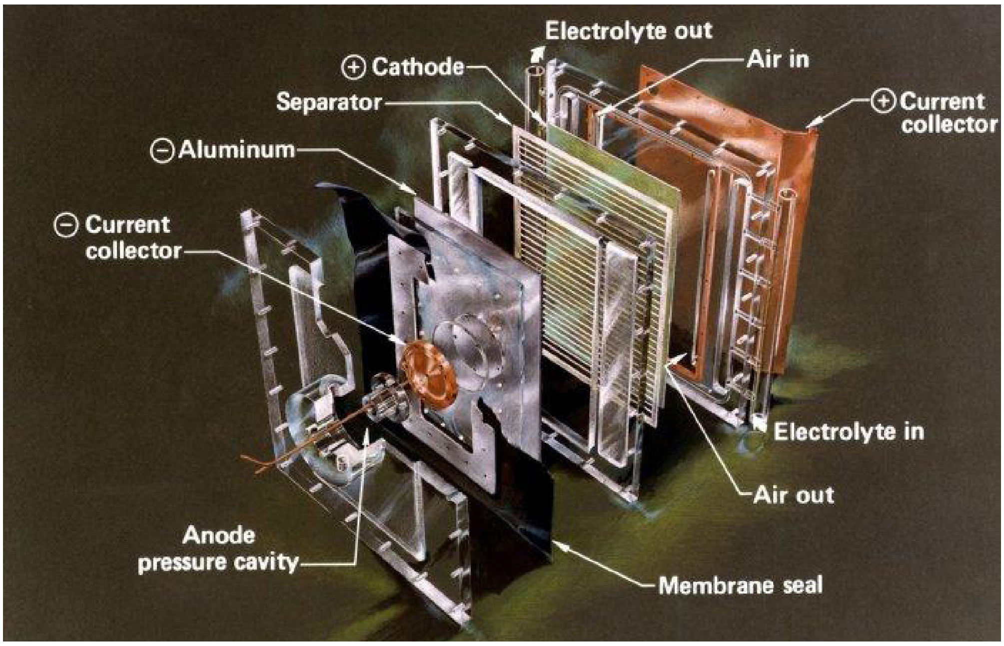
A metal-air battery consists of several principal components. The primary elements include a metallic anode (typically zinc or aluminum), an oxygen cathode, and an electrolyte.

The oxygen cathode is a hollow air-filled structure that allows atmospheric oxygen to circulate freely within the battery, thereby supplying the oxygen required for the electrochemical reaction.

The electrolyte is typically an alkaline solution, such as potassium hydroxide (KOH), which serves as the ionic conductor between the electrodes while maintaining charge balance throughout the electrochemical process.

The operating principle of a metal-air battery is based on the oxidation of the metallic anode. During discharge, the metal releases electrons into the external electrical circuit while simultaneously forming metal ions within the electrolyte.

Figure 2.



These metal ions migrate through the electrolyte toward the oxygen cathode, where they react with atmospheric oxygen and water to form metal oxides. During this electrochemical reaction, electrons are released and returned to the external electrical circuit, thereby sustaining the flow of electric current.

Accordingly, a metal-air battery generates electrical energy through an electrochemical oxidation-reduction (redox) reaction occurring between the metallic anode and oxygen supplied from the surrounding atmosphere.

Design of an Aluminum-Air Battery

The operating principle of an aluminum-air battery is relatively simple. The system utilizes aluminum alloy plates as the anode, water or an alkaline electrolyte as the electrolyte, and an air electrode as the cathode. Atmospheric air is drawn into the air-cathode assembly, which contains a catalyst.

The oxygen contained in the air is separated and reacts with water to form hydroxide ions (OH^-). These ions subsequently participate in an electrochemical reaction with the aluminum anode, resulting in the formation of aluminum hydroxide ($Al(OH)_3$). This electrochemical process releases energy in the form of electrical power.

Types of Metal-Air Batteries

Metal-air batteries are available in several configurations, each utilizing a different metal as the active anode material. The principal types include:

Zinc-Air Batteries. These batteries employ zinc as the metallic anode and atmospheric oxygen as the oxidizing agent. They offer high energy density and are suitable for applications requiring extended operating time, including electric vehicles and unmanned aerial vehicles (UAVs).

Lithium-Air Batteries. These systems utilize lithium as the metallic anode while oxygen from the atmosphere serves as the oxidant. Their exceptionally high theoretical energy density makes them attractive for electric vehicles and other applications requiring high-capacity energy storage.

Aluminum-Air Batteries. These batteries employ aluminum as the metallic anode and atmospheric oxygen as the oxidizing agent. Owing to their high energy density, they are suitable for a broad range of applications, including unmanned aerial vehicles, electric bicycles, and backup power systems.

Aluminum-Air Battery Technology

Aluminum-air battery technology offers a number of significant advantages. Aluminum is lighter than many conventional battery materials, is abundant in nature, and is widely available through established industrial supply chains.

In addition, the aluminum hydroxide produced during battery operation can be recycled and converted back into metallic aluminum, thereby supporting a circular materials cycle.

Furthermore, aluminum-air batteries are reported to achieve an energy density of approximately 8 kWh/kg, compared with approximately 1–1.5 kWh/kg for conventional lithium-ion and related battery technologies. Consequently, even if only half of the theoretical energy density is achieved under practical operating conditions, an aluminum-air battery could theoretically provide approximately four times the driving range of an equivalent lithium-ion battery system.

Advantages and Limitations of Metal-Air Batteries

Advantages

- High energy density. Metal-air batteries offer significantly higher energy density than most conventional battery technologies, enabling substantially longer operating times;
- Long storage life. These batteries can remain in storage for many years without significant degradation of their performance characteristics;
- Environmental compatibility. Metal-air batteries do not contain heavy metals such as lead or cadmium, thereby reducing potential environmental risks.

Limitations

- Limited rechargeability. Metal-air batteries generally provide a limited number of charge-discharge cycles because the oxidation reaction of the metallic anode is not fully reversible;
- Sensitivity to environmental conditions. Certain metal-air battery chemistries are sensitive to moisture and uncontrolled exposure to atmospheric oxygen during storage;
- Application-specific suitability. These batteries are primarily intended for applications where high energy density

is of greater importance than repeated rechargeability.

Zinc-Air Batteries as an Alternative to Lithium-Ion Technology

At present, zinc-air batteries are widely regarded as one of the most promising alternatives to conventional lithium-ion batteries.

Although lithium-ion batteries provide high energy density, they are also associated with several well-recognized limitations. Under unfavorable operating conditions, they may overheat and, in rare cases, experience thermal runaway, resulting in fire or explosion.

In addition, the extraction of raw materials used in lithium-ion batteries – particularly lithium and cobalt – has attracted increasing environmental and ethical concerns. Mining, processing, and disposal of these materials may adversely affect both the environment and human health. For example, cobalt mining in certain developing countries has been associated with child labor and the exploitation of migrant workers.

By comparison, zinc-air batteries are capable of delivering many of the advantages of lithium-ion systems while eliminating the risk of thermal runaway. They also do not require external cooling systems during normal operation.

Furthermore, because zinc-air batteries utilize atmospheric oxygen as the cathode reactant and zinc as the anode material, their manufacture requires fewer rare or environmentally problematic raw materials.

Applications of Metal-Air Batteries

Metal-air batteries have a broad range of military, commercial, and civilian applications.

Military applications benefit from their high energy density and long storage life. These batteries are widely used in communication equipment, optical instruments, portable lighting systems, and unmanned aerial vehicles.

Commercial and civilian applications include electric vehicles, unmanned aerial systems, high-energy portable equipment, and numerous other technologies requiring lightweight, high-capacity energy storage.

Metal-air batteries are also well suited for emergency and backup power systems, including emergency lighting, alarm and notification systems, automatic fire protection systems, telecommunications infrastructure, and other critical facilities requiring reliable standby power.

Despite their numerous advantages, the widespread adoption of metal-air batteries in consumer applications remains limited because of their relatively high manufacturing cost and technological complexity. Nevertheless, continuing advances in materials science and electrochemical engineering are expected to significantly expand their practical applications in the coming years.

Future Development Prospects

Metal-air batteries possess significant potential for future development owing to their high energy density and environmental advantages. The principal directions for the further development of metal-air battery technology include the following:

Technological advancements. Battery manufacturers and research organizations continue to improve metal-air battery technology by increasing energy density, enhancing electrochemical efficiency, extending operational lifetime, and reducing manufacturing costs.

Expansion of applications. Metal-air batteries are expected to find wider application across numerous industries, including the automotive, aerospace, defense, and industrial sectors. Potential applications include electric vehicles, unmanned aerial vehicles (UAVs), portable electronic devices, and stationary backup power systems.

Development of new metal-air battery chemistries. In addition to established technologies such as zinc-air, lithium-air, and aluminum-air batteries, new battery chemistries utilizing more environmentally sustainable and readily available materials are expected to emerge.

Grid-scale energy storage. Metal-air batteries have the potential to become an important component of modern power systems by providing large-scale electrical energy storage capable of supporting grid stability and improving energy security.

Integration with renewable energy sources. Metal-air batteries can be integrated with renewable energy systems, including solar and wind power installations, enabling surplus energy to be stored and subsequently utilized during periods of low renewable energy generation.

Conclusion

Metal-air batteries represent one of the most promising directions in the development of advanced electrochemical energy storage technologies. Their exceptionally high energy density, long storage life, and relatively low material costs make them attractive for applications in defense, aviation, portable electronics, electric transportation, and stationary backup power systems.

Despite these advantages, the technology continues to face several technical challenges, including limited service life, the need for specialized air-management systems, and certain environmental and operational considerations associated with long-term deployment.

Current research and development efforts are focused on improving battery durability, enhancing environmental sustainability, increasing electrochemical efficiency, and expanding the range of practical applications.

One of the most important directions for future development is the introduction of advanced materials capable of improving battery performance, extending operational lifetime, reducing production costs, and minimizing environmental impact.

Accordingly, metal-air batteries constitute a highly promising class of next-generation energy storage technologies with the potential to substantially improve both the energy efficiency and the economic performance of a wide range of electrical and industrial systems.

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FOOD COMPOSITIONS BASED ON BUTTER (Fundamental Differences Between the Churning Process of a Butter-Based Food Composition and Conventional Processes Intended for the Same Purpose)

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Abstract

This article examines the development of innovative food technologies based on the dynamic processing of liquid and semi-consistent multicomponent food systems intended for the production of butter-based food compositions and other combined food products with enhanced nutritional properties. Particular attention is devoted to the analysis of technological, nutritional, environmental, and regional factors that influence the development and commercialization of innovative food products intended to comply with increasingly stringent public health and environmental requirements while taking into account established dietary traditions, climatic conditions, and cultural characteristics of different regions. The article substantiates the feasibility of applying dynamic processing technologies to the preparation of composite, compound, and homogeneously combined food products using dairy-based components as the primary technological medium. The proposed concept integrates the development of specialized technological equipment with nutritional algorithms aimed at producing food compositions characterized by reduced fat content, increased concentrations of vitamins and biologically active compounds, and improved functional and consumer properties. It is concluded that the proposed technological approach represents a promising direction in modern food engineering, creating new opportunities for the production of health-oriented functional food products while supporting the integration of innovative processing technologies into the food industry.

Keywords: *Butter-based food compositions; Food composites; Churning apparatus; Dynamic processing of food composites; Dynamic treatment of butter-based food compositions; Combined food products; Functional food products; Nutritional algorithm design; Vitamin-enriched food compositions; Food compositions enriched with biologically active compounds; Reduced-fat food compositions; Fat content minimization; Health-oriented food technologies*

New food products compositions

Food products, similarly to pharmaceutical products and, to a certain extent, cosmetic products, represent a highly quality-controlled sector of the innovation landscape in which inventors operate.

First and foremost, this field is characterized by the necessity for complete compliance of new products and manufacturing technologies with public health standards and increasingly stringent environmental regulations.

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

At the same time, it is important to acknowledge that the most successful local innovative solutions and inventions, although initially developed for the food industry, may subsequently find applications in broader fields of engineering and technology, thereby serving as effective drivers for the progressive development of integrated multidisciplinary innovations.

The present paper introduces one such promising technological approach.

The proposed technology is based on the hydrodynamic mixing of different liquid components combined with simultaneous churning under a dynamic, periodically repeated, highly developed kinetic regime involving the regeneration of accumulated kinetic energy and its sequential transfer into the processing system.

The proposed innovative process represents a method of dynamic treatment applied to mixed and churned liquid or semi-consistent food components.

To date, the most extensively investigated and frequently applied materials within this process are components derived from various dairy products.

The startup company to be established by the author of this publication is conducting research and development in this field, including the design of specialized technological equipment. The objectives of these scientific investigations, engineering and industrial design activities, as well as the development of nutritional algorithms and dietary programs, are to identify new technological approaches for producing composite, compound, and homogeneously combined food products characterized by the absence or substantial reduction of fat content together with an increased concentration of vitamins and biologically active compounds.

An additional objective of the proposed process is to obtain, without thermal treatment or any other aggressive technological impact on the product, primarily dairy or fermented dairy products, homogeneous mixtures or whipped multicomponent systems that under conventional processing conditions either do not mix at all, mix only poorly, or fail to remain stable over time.

To enable the implementation of the proposed technology under modern industrial production conditions and in accordance with current food quality and safety standards, a further objective of the company is to develop stable and homogeneous food systems composed exclusively of basic food ingredients while maintaining their physicochemical properties and uniformity over extended storage periods.

The final products obtainable using the proposed technology include:

- butter churned from sour cream with an unusually low fat content of no more than 13%;
- butter churned from sour cream enriched with multivitamin additives in the form of a sour cream–carrot juice composition;
- butter churned from sour cream enriched with multivitamin carotenoid additives obtained through the company's proprietary deep-processing technology for chicken eggs;
- butter churned from sour cream with tomato juice;
- butter churned from sour cream with various fruit syrups;
- butter churned from sour cream with honey;
- butter churned from sour cream with garlic and dill;
- butter churned from sour cream modified with ultra-pure egg oil produced using the company's proprietary technology;
- butter churned from sour cream modified with alpha-lecithin obtained

through the company's proprietary deep, waste-free processing technology for chicken eggs;
- butter churned from sour cream modified with albumin obtained through the company's proprietary deep-processing technology for chicken eggs;
- butter churned from sour cream modified with lysozyme obtained through the company's proprietary sequential deep, waste-free processing technology for chicken eggs;
- butter churned from sour cream modified with cocoa butter;
- butter churned from sour cream modified with avocado paste;
- butter churned from sour cream modified with vegetable pastes;
- butter churned from sour cream modified with fruit pastes.

The direct processing of milk and its modification through mixing with other components makes it possible to create new modified combined dairy composites possessing novel functional characteristics and exceptionally high consumer value.

First and foremost, the technology enables the production of a whipped mixture of milk and honey. The formulation employs low-fat milk containing 1% fat, cooled to a temperature of 2–3°C, and natural bee honey in a proportion of 75% milk and 25% honey. The resulting product is homogeneous, stable, possesses an exceptionally delicate and pleasant taste, and exhibits high nutritional value.

Owing to the extensive capabilities of the hydrodynamic mixing and churning apparatus developed within the company's research and development program, it is possible to prepare a wide variety of mixtures based on numerous combinations of liquids, viscous materials, food pastes, and syrups.

The apparatus implementing the proposed technology can be manufactured in a wide range of production capacities. One configuration, designed to produce approximately 1 liter of mixture or approximately 850 g of butter per churning cycle, is intended for use by farmers and may be employed for processing surplus milk.

The apparatus is based on a patented invention utilizing the principle of generating hydrodynamic linear reciprocating kinetic pulsations within the closed volume of a vessel containing the mixed and churned components. The induced hydrodynamic movements are highly efficient, enabling both intensive mixing and churning within a comparatively short processing time while producing an exceptionally homogeneous mixture or composite butter.

The apparatus may be manufactured as a consumer product equipped with a relatively small processing vessel having a capacity of approximately 1 liter. It may be powered either by an electric drive or by a manual drive, the latter significantly reducing manufacturing costs while increasing market accessibility and sales potential.

The apparatus may also be manufactured as auxiliary equipment for cafés and restaurants. In this configuration, the vessel capacity may be increased to approximately 2 liters, and the delivery set may include several interchangeable processing vessels to improve operational efficiency and versatility.

Another configuration may be designed as specialized technological equipment for dairy processing enterprises, where it can be employed for the production of small batches of innovative dairy food composites.

The apparatus may also be manufactured as an automated technological system intended for large-scale and mass production of modified dairy products.

Figure 1. *Illustrates a food composite based on a naturally fermented lactic acid–fat matrix obtained by adding a fermenting agent, such as kefir, to cream separated from whole milk, where the kefir itself is likewise produced through the fermentation of whole milk*

The structural design and operating principle of the proposed apparatus are based on the proprietary inventions developed by the company (Photo 1).

Various additives may be incorporated into the matrix, including, for example, nut pastes, garlic-based sauces, and similar ingredients that do not alter the color of the resulting food composite.

Figure 2. *Illustrates a food composite based on a naturally fermented lactic acid–fat matrix blended with carrot paste in a proportion of 60 parts of the lactic acid matrix to 40 parts of the remaining composite components*

Figure 3. *Illustrates a food composite based on a naturally fermented lactic acid matrix blended with a natural dill–garlic–olive sauce in an initial proportion of 70 parts of the lactic acid matrix to 30 parts of the remaining composite components*

Figure 4. *Illustrates an integrated food composite based on a naturally fermented lactic acid–fat matrix that has been dynamically and homogeneously blended with natural tomato paste and a natural garlic paste sauce in an initial proportion of 70 parts of the lactic acid–fat matrix to 30 parts of the remaining composite components*

Figure 5. *Illustrates a food composite based on a naturally fermented lactic acid matrix dynamically blended with natural bee honey supplemented with nut paste, in an initial proportion of 70 parts of the lactic acid matrix to 30 parts of the remaining composite components*

Of particular importance is the capability to homogenize the food composite simultaneously with the process of mechanical - hydrodynamic churning. This technological feature makes it possible to incorporate components that would otherwise be difficult to disperse uniformly, including products obtained through the company's proprietary deep, waste-free processing of chicken eggs.

These ingredients may be introduced in the form of finely dispersed ultra-pure albumin powder, highly purified liquid alpha-lecithin, gel-like multivitamin carotenoid formulations, or highly purified liquid lysozyme, a natural preservative that imparts unique storage stability and significantly enhances the shelf life of the final product.

Sensory evaluation of the developed food compositions demonstrated exceptionally high organoleptic characteristics across a wide range of component combinations. (Photo 2.)

Figure 6. *Illustrates a food composite based on a homogeneous blend of a naturally fermented lactic acid matrix, prepared exclusively from natural ingredients and containing no additives, preservatives, or stabilizers, dynamically and uniformly mixed with a homogeneous mixture of poppy seeds that had been pre-homogenized with natural bee honey and natural nut paste*

Figure 7. *Illustrates several representative examples from the wide variety of lactic acid–based food composites and integrated food composites that can be produced, even under household conditions, while maintaining a high level of product quality and hygienic safety*

Fundamental Differences Between the Proposed Churning Process for Butter-Based Food Composites and Conventional Churning Technologies

The proposed butter churning process differs fundamentally from existing technologies of the same purpose in several essential structural and technological aspects.

- Churning is performed within a vessel consisting of a cylindrical body closed at both ends by hemispherical end caps provided with centrally located conical openings;
- The churning vessel is assembled from a cylindrical shell with conically machined end surfaces and two hemispherical end caps incorporating matching conical seating surfaces and coaxial conical openings. During assembly, the end caps are aligned with the cylindrical shell through the mating conical interfaces. The complete structure is secured and hermetically sealed by clamping devices mounted within threaded openings of the drive frame. Each clamping device contains a central through-hole equipped with a closure mechanism and incorporates a conical tip aligned with the axis of the opening. During assembly, these conical tips engage the corresponding conical openings of the hemispherical end caps, thereby simultaneously positioning, fixing, clamping, and sealing the internal working volume of the vessel;
- Owing to these design features, the proposed apparatus provides not only

substantial structural differences from conventional churning systems but also significant technological advantages, resulting in improved product quality and a considerably expanded technological operating range for the butter churning process.

Additional Functional Capabilities of the Proposed Process

The proposed apparatus additionally provides several technological advantages that are unavailable in conventional systems.

- The working chamber in which butter churning is performed is fully detachable and reconfigurable;
- During operation, authorized access to the internal processing chamber is possible, allowing additional ingredients to be introduced, processing by-products to be removed, or portions of the product mixture to be withdrawn without compromising the overall operation;
- The conical openings incorporated into the hemispherical end caps enhance disruption and redistribution of the churning mass as it impacts the inner hemispherical surfaces. These openings simultaneously perform multiple functions, including activation, alignment, positioning, sealing, fixation, and, most importantly, serving as technological gateways that permit either the introduction or removal of material, depending on the spatial orientation of the vessel;
- The proposed design allows multiple interchangeable vessels to be used with a single churning apparatus. Consequently, different formulations may be processed sequentially with minimal interruption, including variations in the composition of the lactic acid matrix, fat content, and other formulation parameters;
- The hydrodynamic characteristics of the proposed process are significantly enhanced by the geometry of the vessel. At the end of each linear displacement, the churning mass encounters a hemispherical cavity incorporating a central activating cone. During every impact occurring after each half-rotation of the drive frame, the product undergoes rapid transformation from a cylindrical to a spherical configuration within an extremely short time interval. Thus, deformation and churning occur simultaneously, substantially increasing process efficiency;
- This unique mode of mechanical action creates a kinetically diverse regime of forced deformation in which the product experiences repeated changes in both volume and geometry under the combined influence of multiple dynamic forces. These forces arise from the interaction between the vessel geometry and the kinematic characteristics of the butter-churning apparatus, resulting in highly efficient hydrodynamic processing.

Experimental Evaluation of the Hemispherical End Caps

Testing of prototype hemispherical end caps demonstrated that:

- their design is highly manufacturable;
- they possess excellent mechanical strength;
- they are convenient to operate and maintain;
- they satisfy stringent hygienic requirements;
- they can be manufactured from a wide variety of engineering materials; and
- multiple interchangeable versions of the hemispherical end caps, differing in spherical curvature and the depth of the central conical opening, may be used with the same cylindrical shell while maintaining complete compatibility of all mating interfaces.

Apparatus for Churning Food Composites, Including Composite Butter: Description of the Device and Principles of Its Practical Operation

The proposed apparatus for churning and homogenizing food compositions and composite butter is intended for the efficient production of composite dairy products based on fermented dairy raw materials, primarily sour cream or cream, preferably with a reduced fat content. The initial raw materials or individual components may be subjected to fermentation prior to processing.

Preliminary experimental evaluation demonstrated that the apparatus efficiently produces butter not only from conventional sour cream but also from sour cream supplemented with a wide variety of ingredients, primarily of plant origin.

Representative additives include:

- carrot juice;
- carrot purée or carrot paste;
- tomato juice;
- tomato paste;
- cucumber brine;
- cucumber purée;
- avocado purée;
- kiwi purée;
- sweet pepper purée;
- various squash and zucchini purées;
- fruit purées, including apple, plum, peach, pear, apricot, pineapple, and purées prepared from tropical fruits and vegetables;
- combinations of the above ingredients together with dill, garlic, onion, and lemon;
- prune pulp;
- preserves prepared from chokeberry, sea buckthorn, and other medicinal fruits and berries;
- berry purées prepared from strawberry, wild strawberry, blueberry, blackcurrant, raspberry, mulberry, viburnum, gooseberry, and numerous other berries.

This list is not exhaustive and may be expanded to include fruits, vegetables, and other plant-derived ingredients characteristic of different geographical regions, either individually or in various combinations.

The composition of the resulting composite butter may additionally be modified by introducing vegetable fats during the churning process in order to regulate the ratio between animal-derived and plant-derived lipid fractions.

To maximize application flexibility, the apparatus has been designed to accommodate production of composite butter formulations containing a wide variety of additives and manufactured in different batch volumes.

The capability for rapid reconfiguration to produce composite butter formulations with different ingredients represents one of the principal operational advantages of both the apparatus and the proposed churning technology.

Mixer Vessel Design

The mixer vessel consists of three principal structural components, the most innovative of which have the greatest influence on churning efficiency and on the characteristics of the resulting commercial products.

Cylindrical vessel body

The cylindrical shell incorporates conical recesses at both flange ends. These simultaneously provide hermetic sealing of the working chamber while ensuring precise centering and three-dimensional geometric alignment of the vessel throughout the churning process, thereby maintaining constant spatial relationships between all structural elements and preserving the alignment of the apparatus axes.

Upper hemispherical end cap

The upper hemispherical cover incorporates two coaxially arranged conical surfaces designed for centering, positioning, and sealing the vessel. The upper conical opening, which receives the axial locking force from the fixing mechanism equipped with a closable axial passage, permits all required components of the butter formulation to be introduced into the sealed vessel without disassembling the apparatus.

Lower hemispherical end cap

The lower hemispherical cover incorporates three coaxial conical surfaces intended for centering, positioning, sealing, and removal of process by-products from the internal chamber. The lower conical opening receives axial locking force from a fixing mechanism equipped with a ball valve, allowing liquid by-products generated during butter churning to be discharged while the vessel remains fully assembled and hermetically sealed.

Churning Procedure

The production of high-quality, highly purified, homogeneous butter without additives consists of the following sequence of operations.

Following cleaning after the previous processing cycle, the cylindrical vessel body together with the upper and lower hemispherical end caps are aligned through their mating conical surfaces. The assembly is then positioned within the supporting frame, and the locking mechanisms are tightened along the longitudinal axis until complete engagement of the conical interfaces between both end caps and the cylindrical shell is achieved.

The sealing plug incorporated into the upper locking mechanism is then opened, and the required quantity of sour cream or fermented cream is introduced into the internal chamber of the vessel.

After filling, the sealing plug is closed and the drive frame is set into rotational motion. During operation, the product moves longitudinally inside the vessel, completing one full reciprocating displacement and impacting the hemispherical end surface once during every half revolution of the rotating frame.

Upon completion of the churning cycle, the apparatus is stopped and the frame is rotated until the lower hemispherical end cap occupies the downward position. The ball valve is then opened, allowing the liquid by-product generated during butter churning to be discharged from the vessel.

The locking mechanisms are subsequently released, and the vessel assembly is removed from the frame. Both hemispherical end caps are detached, after which the finished butter is removed from the cylindrical chamber of the mixer vessel. The three structural components are then washed, and, if required, replaced with a clean interchangeable vessel assembly.

When additives or combinations of additives are required, all components are introduced according to the procedure described above.

If ingredients must be incorporated sequentially or at predetermined time intervals, the rotating frame is temporarily stopped before each addition, the sealing plug is opened, the required component is introduced, and processing is resumed.

The ability to introduce ingredients flexibly according to processing time, degree of butter formation, temperature, or other physicochemical process indicators substantially broadens the technological capabilities and operational versatility of the proposed butter-churning apparatus.

Process And Apparatus for Churning Animal-Based Composite Butter From Multicomponent Raw Materials Comprising Plant- and Animal-Derived Ingredients Incorporated Into A Lactic Acid Matrix In Various Proportions

What is Claimed as the Invention

Process

A process for producing animal-based butter, preferably from multicomponent raw materials based on a lactic acid matrix having any desired fat content, including reduced-fat formulations, comprising:

- forming the initial processing composition within the internal chamber of a mixer vessel by sequentially introducing a lactic acid matrix together with additives of plant and animal origin;
- installing the mixer vessel within the mixer drive frame and hermetically sealing its internal chamber by axially fixing hemispherical end caps;
- mounting the mixer drive frame within the powered support of the mixer while maintaining a predetermined angle between the longitudinal axis of the mixer vessel and the axis of rotation of the drive spindles, said angular relationship remaining constant throughout the entire churning process;
- reciprocating the initial composition along the longitudinal axis of the mixer vessel, with the moving mass impacting the internal surfaces of the hemispherical end caps once during every half revolution of the drive spindles;
- reversing the direction of movement of the processing composition during every half revolution of the drive spindles;
- accumulating the kinetic energy of the moving mass each time its direction of movement is reversed;
- discharging the technological by-product generated during the churning process;
- depressurizing and removing the mixer vessel from the drive frame;
- separating the hemispherical end caps from the cylindrical vessel body and removing the churned product from

the cylindrical chamber of the mixer vessel.

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PSYCHOLOGICAL ASPECTS AND NUANCES OF PRODUCT MARKETING (Modern multidisciplinary digital technologies incorporating artificial intelligence and artificial neural network elements, together with the psychological aspects and nuances of marketing products developed on the basis of, and further advancing, these technologies)

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Abstract

This publication examines modern multidisciplinary digital technologies incorporating artificial intelligence (AI) and artificial neural network (ANN) elements, together with the psychological aspects and marketing principles associated with innovative products developed on the basis of, and through the advancement of, these technologies.

Particular attention is devoted to the integration and psychological adaptation of the Theory of Inventive Problem Solving (TRIZ) and the Algorithm of Inventive Problem Solving (ARIZ) to contemporary approaches to the commercialization of innovative products, high-technology projects, and digital solutions. The publication analyzes methods for evaluating the commercial potential of innovative products while taking into account the requirements of modern patent legislation, including the assessment of the non-obviousness of technical solutions as one of the fundamental criteria for patentability under United States patent law.

The publication investigates the influence of digital technologies, software systems, artificial intelligence, and artificial neural networks on the development, commercialization, market positioning, and legal protection of innovative products. It demonstrates that the increasing technological complexity of modern products requires the integration of engineering analysis with advanced psychological approaches to assessing innovation potential, market acceptance, and commercial viability.

Special consideration is given to the development of a comprehensive preliminary evaluation methodology based on a structured assessment framework consisting of 44 interrelated evaluation criteria designed to analyze innovative ideas at the earliest stages of development. The proposed methodology enables the assessment of commercial potential, technological originality, market competitiveness, patent prospects, and the psychological factors influencing the perception and successful commercialization of innovative products.

The publication further emphasizes the necessity of adapting the classical principles of TRIZ and ARIZ to the realities of the modern innovation economy, where the success of a technological solution depends not only on its engineering originality but also on its commercial feasibility, intellectual property protection, market strategy, and psychological acceptance by potential users and investors.

The methodological approaches presented in this publication may be applied in the development, expert evaluation, commercialization, and strategic management of innovative products based on advanced digital technologies, artificial intelligence, and artificial neural networks. They may also serve as practical tools for specialists in innovation management, technology commercialization, engineering entrepreneurship, strategic marketing, and high-technology product development.

Keywords: *Digital technologies; multidisciplinary digital technologies; product marketing aspects; evaluation sheet components; the fundamental nature of all evaluation sheet elements; application of the Theory of Inventive Problem Solving (TRIZ) to enable personnel to generate innovative ideas and transform them into practical end results; the impact of artificial intelligence and artificial neural network elements on the optimization potential of monitoring and control systems; identification of non-obvious analogues of future inventions through comprehensive analysis of biological, biomedical, and other intelligent technological systems; biomimetic engineering approaches; biomechanical research; computer modeling; innovation methodology; intelligent technological systems; smart technologies; engineering innovation; digital transformation; systems engineering*

Introduction

Integration of the Algorithm of Inventive Problem Solving with Modern Commercialization Theories

At the time when the Theory of Inventive Problem Solving (TRIZ) was developed, it was widely believed that any qualified engineer or professionally trained specialist, provided with the methodological principles of TRIZ, could generate innovative ideas and successfully transform them into practical technical solutions. Owing to this prevailing perception, the newly developed methodology was rapidly accepted by the engineering and scientific communities.

For a considerable period, the fundamental principles, laws, and methods of TRIZ corresponded to the technological capabilities and engineering requirements of their time.

However, the rapid development of modern digital technologies raises a number of fundamentally important questions. What do these classical principles represent under contemporary technological conditions? How have advanced computing technologies and modern processor architectures influenced their integration capabilities? To what extent will the incorporation of artificial intelligence (AI) and artificial neural network (ANN) elements transform the optimization potential of intelligent monitoring and control systems? These represent only a small number of the questions requiring comprehensive scientific analysis.

One of the most significant contemporary trends is the systematic search for non-obvious engineering analogues within biological and biomedical systems, as well as within other intelligent technological environments. Modern biomechanical research, biomimetic engineering, and computer modeling increasingly provide the conceptual foundation for future inventions by revealing innovative technical principles derived from naturally occurring biological mechanisms.

These developments raise another important question: how can such approaches be effectively integrated with the established principles of TRIZ, ARIZ, and contemporary patent and licensing strategies?

Today, many of the most valuable and commercially promising inventions originate from discoveries inspired by living biological systems. These discoveries stimulate the development of fundamentally new engineering concepts, unconventional technical solutions, and innovative technological methods that form the basis of intelligent engineering infrastructures and next-generation smart technologies.

Looking ahead, the introduction of quantum computers and their processor equivalents, integrated with artificial intelligence and artificial neural network technologies, is expected to substantially expand the scope, functionality, and application domains of intelligent technological systems.

The following sections present representative examples illustrating how integrated multidisciplinary concepts generate innovative technological environments characterized by non-obvious engineering solutions, the transformation of supersystems and interconnected subsystems, and the creation of fundamentally new technological architectures possessing a high degree of innovation and commercial potential.

Integration of the Algorithm of Inventive Problem Solving with Modern Commercialization Theories

The Theory of Inventive Problem Solving (TRIZ) and its subsequent Algorithms of Inventive Problem Solving (ARIZ) were developed during a period in which the commercialization of technological innovations received relatively little attention. At certain stages of their development, commercial considerations were intentionally subordinated to purely technological objectives, resulting in engineering solutions that were often detached from economic realities and practical market requirements.

As a consequence of this historical approach, many inventors educated within the classical TRIZ methodology became exceptionally skilled at generating technical innovations but remained insufficiently prepared for the challenges of commercialization, intellectual property management, competitive market environments, and innovation-based entrepreneurship. While they demonstrated outstanding creative abilities in developing new technical solutions, they frequently lacked the practical knowledge required to transform these innovations into commercially successful products capable of providing appropriate economic returns for their intellectual efforts.

For this reason, it is essential to evaluate not only the technological feasibility of an innovative idea but also the necessity of initiating the innovation process itself. Equally important is the ability to forecast multiple commercialization scenarios, assess market opportunities, and estimate the probability of successful implementation at the earliest stages of development.

To address these challenges, the author proposes the application of a comprehensive preliminary evaluation methodology based on a structured assessment framework consisting of 44 evaluation criteria. This assessment sheet is intended to facilitate the systematic analysis of innovative ideas by simultaneously considering their technological originality, commercial potential, patentability, market prospects, and strategic feasibility before significant development resources are committed.

Assessment Sheet Components

Each of the 44 components of the Assessment Sheet examines a specific aspect of an idea. The Assessment Sheet, available for download from www.prenhall.com/willitfly, is reproduced in Appendix IV. All calculations may be performed manually using a calculator or by entering the relevant values and formulas into an Excel spreadsheet. Each component is assigned a numerical score.

1. Urgent Unmet Need
2. Explainable Uniqueness
3. Sustainable Differentiation
4. Readiness for Immediate Demonstration
5. Good Competition
6. Bad Competition
7. Attractive Pricing Policy
8. Customers Willing to Purchase a Product That Does Not Yet Exist
9. Strength of Evidence of Demand
10. Staying Ahead of the Market
11. Ambush Strategy
12. “Hot” Market
13. Confidence and Fearlessness
14. Fulfillment of Commitments
15. Resilience
16. Passion
17. Management Competence
18. Integrity and Reliability

19. Ethics of Success
20. Attractiveness to Lobbyists
21. Available Cash
22. Revenue Exceeding Costs
23. Delivery Service Advantages
24. Availability of Resources
25. Market Leadership and Dominance
26. Market Penetration Strategy
27. Strategy for Crossing the Chasm
28. Intellectual Property Protection
29. Partnership Potential
30. Selection of the Right Location
31. Quality of the Contingency Plan
32. Unfair Advantages
33. Management of Capital Requirements
34. Limited Cash Requirements Prior to Business Launch
35. Visible Capital
36. High Potential Value
37. Predictable Results
38. Taboos
39. Showstoppers
40. Ostrich Syndrome
41. Connections with High-Flying Individuals
42. A Compelling and Persuasive Story
43. Connections with Government and Political Decision-Makers
44. The Path of Least Resistance, or Low-Hanging Fruit

Check that the spreadsheet functions correctly. Enter a score of 10 in every cell intended for the evaluation of an individual component. The total score should then equal 860.

Divide this figure by the weighted average score assigned to your idea in order to determine its overall rating. A result of 70 points or more is considered a passing score.

The degree of subjectivity and the role of intuition vary depending on the nature and subject matter of the idea being evaluated. The following sections examine the role of intuition, methods for evaluating and weighting individual components, and an additional method for applying the Assessment Sheet. They also explain what should be done when a particular component receives a low score, how calculations may be adjusted when a component appears irrelevant, how to maintain a realistic perspective, how to synthesize the scores, and how to address overlap – that is, situations in which two components cover the same underlying concept.

After reviewing the basic principles of assessment management, the discussion proceeds to a detailed examination of the individual sections represented by each component.

Examples of calculations are provided for every component so that readers can understand how it may be applied in real-world situations. From time to time, examples drawn from personal professional experience are also presented. The underlying assumptions are described in detail, although the names of the individuals involved have been changed.

Subjectivity and the Role of Intuition

At the earliest stage in the emergence of an idea, there is often a tension between objectivity and subjectivity. If you were completely objective, you might simply discard an idea that is, in fact, genuinely promising.

Objectivity may be regarded as part of the strategic planning process. Accordingly, the key to using the Assessment Sheet is intuition, which Webster's Dictionary defines as "the act or process of coming to direct knowledge or certainty without reasoning or inferring; immediate cognition." In an environment where research and objective analysis are highly valued, the possibility of applying an intuitive evaluation tool may appear particularly intriguing.

It should be emphasized that objectivity resulting from thorough research has an essential place in the decision-making process. At the same time, almost every major innovation began with a degree of subjectivity and intuition. General Motors, AT&T, Motorola, Procter & Gamble, and virtually every company included in the Fortune 500 began with little more than an initial insight or intuition – before the first automobile was sold, the first telephone call was made, or the first portable transceiver was created.

Unfortunately, the objective, or non-intuitive, approach to new ventures in corporate America may at times be excessively influenced by internal corporate politics. When large organizations attempt to launch a new business, rational analysis may, for one reason or another, be overridden by executive-level political considerations. A notable example is Motorola's experience with the Iridium project, a global satellite cellular communications system. Professionals outside the company never regarded Iridium as a commercially viable project.

At the same time, many remarkable success stories are associated with less widely known organizations.

One particularly interesting example concerns the U. S. Navy submarine USS Scorpion (SSN-589), which sank on May 22, 1968. Six months later, it was discovered at a depth of more than 3,000 meters, approximately 400 miles southwest of the Azores. The submarine was located after several highly qualified experts in marine modeling and mathematics calculated its probable position by solving a decision problem formulated by John Craven, a civilian specialist engaged by the U. S. Navy to manage the investigation.

The experts reached a collective conclusion that a torpedo tube had been activated and that, in order to trigger the torpedo's internal engine shutdown mechanism, the submarine had changed course by exactly 180 degrees. Based on this collective assumption, the search team succeeded in locating the submarine only approximately 200 yards from the predicted coordinates. In this case, intuition contributed directly to solving the mystery.

Numerical Values in the Assessment Sheet

The following section describes two calculation methods used for each component. The first is referred to as scoring, and the second as weighting. Each business idea is assigned its own unique score, whereas the same component retains the same weight when applied to different ideas.

Scoring

The score ranges from +10 to –10. The first step is to determine whether the score should be positive or negative.

Ultimately, the evaluator is assessing the risks and benefits associated with a particular action or form of behavior. Although one may not consciously recognize it, this is something people do every day. For example:

- Is it worth spending additional time overtaking a slow-moving vehicle in order to move into the far-right lane of a motorway?
- Would I benefit from switching to a different cleaning product?
- Is it worth risking an expired parking payment?

In each of these situations, we compare the likelihood of success with the possible consequences of failure.

Another important consideration is the need to ensure that the assigned score is sufficiently well founded. A critical element of the intuitive approach is therefore an informed assumption based on relevant knowledge.

Sherry Sontag et al., *Blind Man's Bluff: The Untold Story of American Submarine Espionage*, Chapter 5, Thorndike Press, 2000.

A score may always be revised later if further reflection indicates that another value would be more appropriate.

How should each component be evaluated? We generally begin with a pass/fail assessment, using 7 points as the threshold value.

Does the component deserve a score higher than 7? If so, by how much? Does the idea merit 7, 8, or 9 points? Or is it sufficiently strong to receive a perfect score of 10?

Most readers are likely familiar with this type of scale, and the method should therefore be relatively easy to apply.

If the component fails to meet the required standard, should it receive 6 points? Or should the score be reduced to 5, corresponding to approximately 50 percent, or perhaps to 4 or 3? Should it receive a firm score of zero because it completely fails to satisfy the relevant criteria? Alternatively, does it possess some residual value that justifies a score of 1 or 2?

We assign a score of 1 or 2 to components that would otherwise merit zero but nevertheless retain some limited or appealing value.

In some cases, a component may be so weak – even in a project that ultimately becomes successful – that a score of zero is insufficient. In such circumstances, the component should be evaluated using the negative portion of the scale.

For example, Orion Satellite Corporation attempted to compete with the global Intelsat telecommunications cartel. The U. S. representative and access provider, Comsat, which held the exclusive right to operate through Intelsat satellites, charged approximately ten times the price of comparable domestic satellite services for essentially identical technology.

We believed that Orion would be able to provide better service at a significantly lower cost. However, approximately 130 countries were aligned against the company, and Orion therefore received an extremely low score for the component referred to as "Showstoppers."

In other words, the component was not merely somewhat weak; it represented a major obstacle and therefore required a negative score. If a component indicates an almost inevitable failure of the project, it should be assigned a score of –10.

The Orion showstopper example will be examined in greater detail later.

Weighting

Each component has its own specific **weight**, which must be multiplied by the assigned score. Weighting reflects the fact that certain components carry greater significance and are therefore more important than others.

Rather than providing an extensive description of a highly detailed weighting methodology, we adopted a simplified system and assigned each component one of three classifications: minimum, medium, or maximum weight. Components with minimum, medium, and maximum weight are multiplied by coefficients of 1, 2, and 3, respectively.

Because the Assessment Sheet is inherently intuitive, the weighting values reflect experience-based judgment. The weight assigned to a particular component remains constant for all ideas, whereas the score will naturally vary from one idea to another.

For example, whenever an urgent unmet need is evaluated, that component will carry a weight of 3, regardless of whether the project involves launching a new airline or developing a residential care facility.

Bonus Application

The Assessment Sheet may be used not only to evaluate the initial viability of a business venture but also, after several years of operation, as a diagnostic and adjustment tool.

As the entrepreneur gains experience and accumulates and synthesizes additional information, the Assessment Sheet becomes increasingly accurate. Ultimately, it represents a snapshot of perceived reality at a given point in time.

A more reliable assessment is therefore likely to result from a sequence of several such snapshots rather than from a single evaluation.

Individual Low Scores

No single component score should be considered so low that it automatically prevents a venture from moving forward. Low scores may be compared to a map of minefields across the business landscape. If the hazards are identified and neutralized, the project may still succeed, even when some individual scores remain low.

As noted above, Orion Satellite Corporation received the lowest possible score for the "Showstoppers" component. The company faced opposition from 130 countries united within an active and legally established cartel. Accordingly, the project received a score of –10 for this component, which, after applying the maximum weighting factor, resulted in a weighted score of –30.

Was this fatal to the project? Not at all. The company ultimately succeeded.

The essential requirement is persistence and the continued search for ways to improve weak areas. At some point, a component may reach an acceptable passing level.

The key indicator in Assessment Sheet analysis is therefore the total weighted score. The central question is whether the overall result can reach at least the passing threshold of 70 percent.

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INNOVATIVE LOGISTICS OF SMART AIRFIELD GROUND HANDLING TECHNOLOGIES (Innovative infrastructure components of a smart airfield ground handling technology complex for energy supply, backup energy storage, water supply and purification, water regeneration and recirculation, clean air supply, air regeneration and oxygen enrichment, and integrated issues of active real-time monitoring and control of these components and their interrelationships)

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Abstract

The article examines methodological approaches to the development of innovative technical solutions for smart homes, smart industrial facilities, and their infrastructure components, with particular attention to systems supporting airfield ground handling technologies. It emphasizes the importance of a comprehensive systems approach that integrates technical, technological, economic, environmental, and commercial considerations throughout the innovation process. The study also highlights the role of patent and licensing strategies and the assessment of the commercial potential of engineering solutions.

The article presents the concept of an autonomous modular energy-generating unit designed as a backup power source for smart building infrastructure. The proposed solution is based on a multistage energy conversion process, innovative fuel compositions, electromagnetic torque amplification, and planar low-speed electric generators to improve energy efficiency and operational reliability. The integration of advanced infrastructure technologies with intelligent control systems provides a foundation for commercially viable, energy-efficient, and environmentally sustainable engineering solutions for next-generation smart infrastructure.

Keywords: *Smart airfield ground handling technology complex; Innovative infrastructure components of a smart airfield ground handling technology complex; Components of a smart airfield ground handling technology complex for energy supply; Components of a smart airfield ground handling technology complex for backup energy storage; Components of a smart airfield ground handling technology complex for water supply and water purification; Components of a smart airfield ground handling technology complex for water regeneration and recirculation, and clean air supply; Integrated issues of active real-time monitoring and control of these components and their interrelationships; Innovative logistics of a smart home, a smart industrial facility, and their infrastructure components*

Introduction to the innovative logistics of smart homes, smart industrial facilities, and their infrastructure components

The process of developing a technical solution that constitutes an invention while also possessing commercial potential requires extensive analytical preparation, numerous comparative evaluations, and the identification of those parameters and characteristics that, under current conditions, are capable of attracting investor interest and generating the required level of market demand.

The era of isolated inventions that could be implemented independently and without reliance on integrated technologies or the interconnected conditions of modern life has passed. Contemporary technical solutions must take into account environmental and sustainability considerations, as well as the social aspects of their application.

Without a systematic approach and a clearly defined methodology, it is extremely difficult for inventors and technology developers to navigate this complex environment.

The first step is to evaluate the proposed technological solution and systematically compare its characteristics with those of existing technical solutions and technologies that have previously achieved, and continue to achieve, commercial success.

Market requirements are often highly subjective. Therefore, it is essential to establish the relationship between subjective market expectations and objective constraints associated with the performance limits of technological equipment, the availability of suitable materials, production costs, and the practical feasibility of manufacturing operations, while ensuring that these factors do not compromise the unique advantages and distinguishing features of the proposed invention.

It is recommended that the preliminary analysis be conducted according to the following framework.

Introduction

Characterization of the integrated nature of the proposed technology.

Analysis of the proposed technology to determine whether it is based exclusively on well-established and repeatedly validated physical principles and laws implemented in a compact integrated engineering or technological solution.

Analysis of the proposed technology and the device (or method) for its implementation to determine whether they can be applied in real industrial systems without any modification of their design or operating principles.

Analysis of the proposed technology to determine whether it utilizes only well-established and widely used components and their combinations.

Analysis of the proposed technology to assess the possibility of integrating novel components with well-established ones in various combinations formed during the proposed process through the properties and characteristics of the device used to implement the proposed technology.

Analysis of the proposed technology to evaluate its level of versatility and flexibility, enabling the implementation of flexible technological schemes within the same device or method used to realize the technology.

Analysis of the proposed technology to determine the possibility of incorporating, or the presence of, a system for process management, monitoring, and parameter control based on a minimum number of monitored and regulated process parameters that have a direct relationship with, and immediate influence on, the efficiency of both the process itself and the device during its operation, while ensuring the required technological, energy, and environmental performance.

Process description

Possible components of the proposed technology and device.

Description of device design options, taking into account the possibility of integrated activation and improvement of the efficiency of its fundamental operating principles.

Description of the process advantages achieved through the operation of the proposed device due to the properties and characteristics of the device itself.

Description of well-established and tested technologies that preceded the development of the proposed technology and positively influenced its performance parameters and characteristics.

Characteristics of the proposed technology.

Sequential description of the technological stages of the proposed process.

Schematic diagram of the devices and components included in the industrial system using the proposed integrated technology.

Operating procedure of the proposed device, illustrated by its implementation in a real industrial system.

Operational characteristics of the proposed technology during the initial stages of application.

Operational characteristics of the proposed technology during the subsequent stages of application.

Methods for regulating the main operating characteristics of the proposed technology; the possibility of remote control of the regulation process; the main regulated parameters; feedback during regulation.

The main operating parameters of the proposed technology that determine its advantages over existing alternatives and technologies.

Description of the proposed process or the integrated nature of the proposed technology; advantages arising from the implementation of the proposed process or technology.

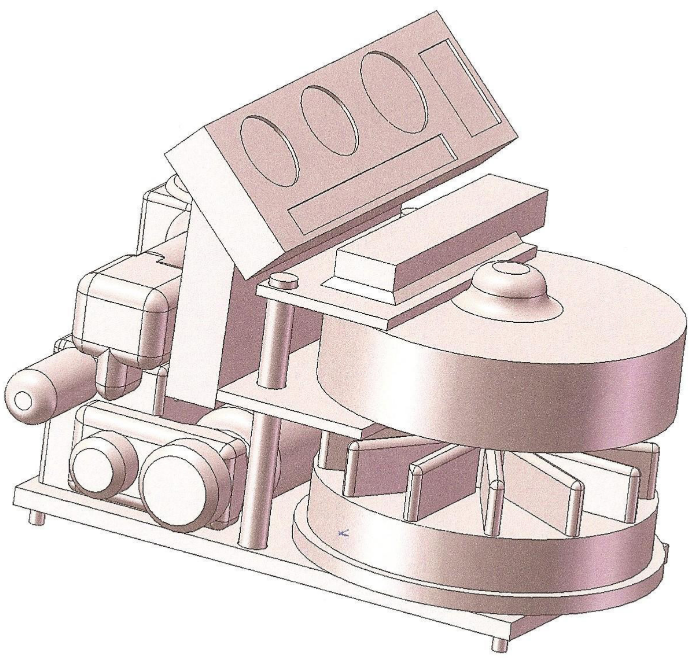
Expected and calculated characteristics of the proposed process.

Technical and commercial advantages of applying the proposed technology; its potential integrated nature and the impact of this aspect.

Working with the patent and licensing strategy flowchart.

After completing the above analysis, a sufficient amount of information may be accumulated to complete the patent and licensing strategy flowcharts.

Figure 1.



Depending on the complexity of the technical solution, the structure of the flowcharts may vary significantly. However, they will undoubtedly be more effective and reliable if, prior to their completion, a forecast is made of the future development of the field of technology to which the proposed technical solution or the subject of the future invention belongs.

A wide range of information tools is currently available for preparing such forecasts. Their analysis, combined with an understanding of the technical and commercial essence of the proposed invention, makes it possible to produce a sufficiently accurate forecast.

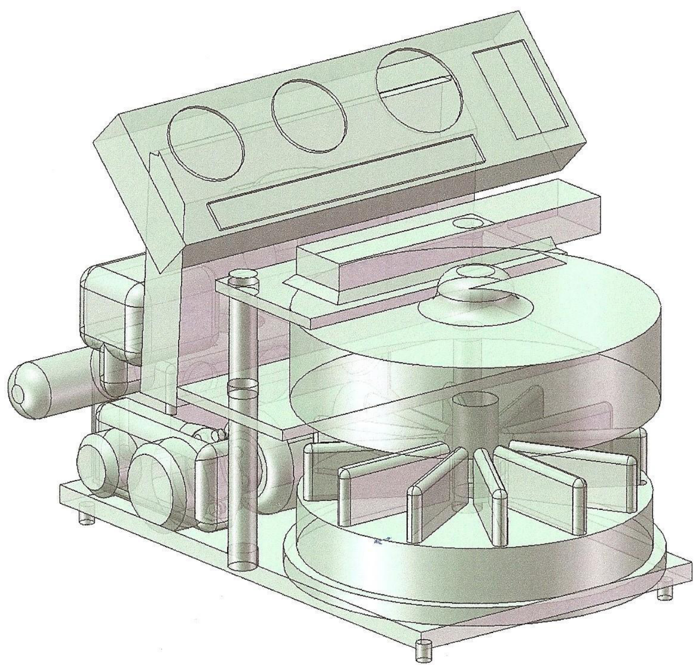
Thereafter, the initial sections of the patent and licensing strategy flowchart may be completed using the proposed template, and the planned implementation process can begin.

A smart home, and especially a smart industrial facility intended for the installation of equipment supporting airfield ground handling technologies, like any other building, requires a reliable, cost-effective, easy-to-manage, and independent backup energy source.

The following solution is proposed for this purpose: an autonomous modular energy-generating unit for installation within the infrastructure of a smart home as an independent backup power source. The unit is based on integrated engineering solutions aimed at reducing the consumption of organic fuels in internal combustion engines, achieving highly efficient energy conversion with increased output torque, and employing planar technology in the design of low-speed electric generators.

The proposed unit is designed according to the principle of sequential multistage energy conversion, in which different forms of energy are transformed step by step, with the equivalent power characteristics being progressively amplified at the output of each conversion stage.

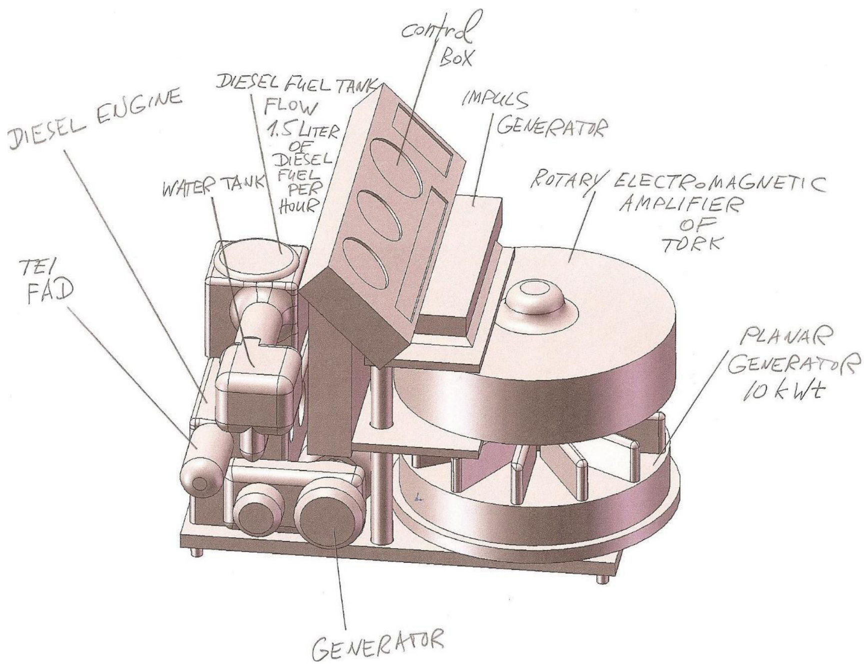
Figure 2.



1. The first stage of energy conversion involves transforming the energy released from the combustion of organic fuel into the mechanical rotational energy of the output shaft of an internal combustion engine, which serves as the primary energy conversion unit.

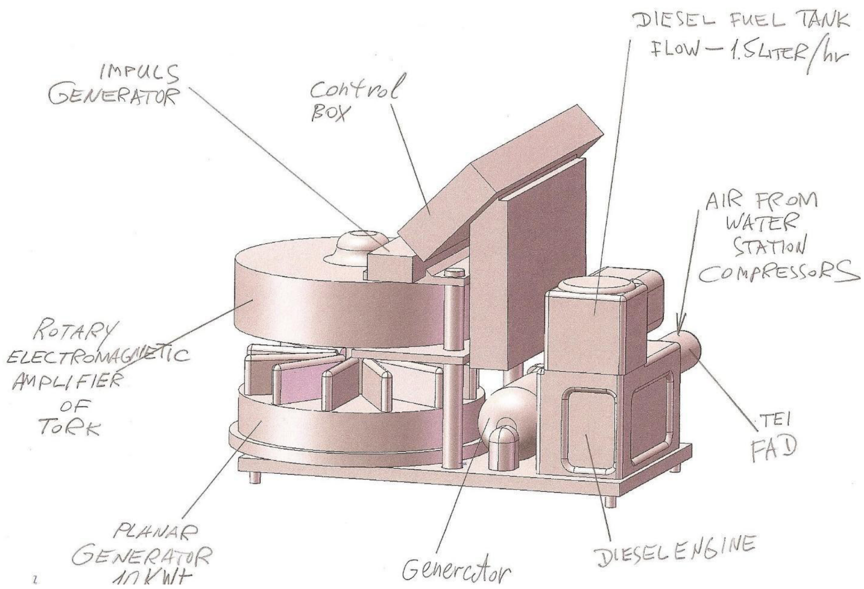
The energy efficiency improvement at this stage is achieved through the use of a fuel composite consisting of a hydrodynamically mixed and aerodynamically foamed fuel composition containing 70% ethanol and 30% synthetic water. The synthetic water is obtained from atmospheric moisture containing traces of ethanol vapor, another alcohol, or gas condensate. Alternatively, highly purified water may also be used.

Figure 3.



2. The second stage of energy conversion involves transforming the mechanical rotational energy of the output shaft of the internal combustion engine into electrical energy with predetermined electrical characteristics.

Figure 4.



3. The third stage of energy conversion involves generating electrical current pulses with predetermined parameters.

4. The fourth and most important stage of energy conversion involves transforming the current pulses into torque at the output shaft of the torque converter–amplifier. The amplification effect is achieved through two factors. The first factor is kinematic, and it involves the use of a rotary converter that transforms linear motion into rotational motion, thereby eliminating dead centres and the energy losses associated with overcoming them. The second factor is electromagnetic, and it involves the use of armoured electromagnets with a specially designed magnetic circuit and a specially designed solenoid, together with additional structural advantages resulting from the combination of the core and the planar design of the solenoid coil.

5. All these advantages determine the efficiency of electromagnets belonging to the category of so-called WARM OR COLD magnets, which generate a pulling or pushing force an order of magnitude greater than the equivalent electrical energy consumed to produce it.

6. The fifth stage of energy conversion involves transmitting torque to the shaft of a planar low-speed generator and producing electrical energy as the final output of the unit.

7. The use of a planar low-speed generator makes it possible to utilize the power characteristics of the electromagnets in their most efficient operating mode, since the lower the operating frequency of the electromagnet, the longer its operating cycle, and the more time is available for the restoration of the magnetic properties of the combined magnetic circuit.

8. All of the fundamental technical solutions incorporated into the proposed unit possess substantial novelty and constitute inventions. These include:

– The use, as the fuel mixture for the internal combustion engine, of a mixture consisting of an organic component and an inorganic component.

– The use of hydrodynamic activators, operating on the Bernoulli principle, for mixing the organic and inorganic components of the fuel mixture within a continuously flowing stream of the organic component.

– The use of aerodynamic activators, operating on the Bernoulli principle, for foaming the composite–compound fuel mixture within a continuously flowing stream of the fuel mixture.

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ECOSYSTEM-BASED SMART WORKSTATION EQUIPMENT FOR FOOD PROCESS ENGINEERS (Real-Time Monitoring and Control of the Environmental Safety Level of Food Manufacturing Processes Using Granulated Zeolite and Vortex Generation Technology)

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Abstract

The article discusses the development of ecosystem-based smart workstation equipment for food process engineers and its innovative modifications incorporating vortex-generation technology. Particular attention is devoted to the concept of an intelligent engineering workplace designed to ensure real-time monitoring and control of the environmental safety of food manufacturing processes through the integration of advanced engineering solutions, artificial intelligence (AI), artificial neural networks (ANNs), and intelligent process-control technologies.

Within this concept, activated carbon-carbon fabrics and their innovative modifications are considered as key functional elements for achieving the ideal final result in environmentally sustainable food manufacturing and food service operations. The proposed ecosystem-based smart workstation integrates intelligent monitoring, environmental control, process management, and analytical support into a unified digital infrastructure capable of continuously evaluating the environmental conditions and operational parameters of food production systems.

The article also examines the application of integrative modules for electronic systems, including laser diodes equipped with intensive cooling systems based on diamond-copper composite materials. These engineering solutions are presented as essential components of intelligent food manufacturing equipment, providing enhanced thermal management, operational reliability, and long-term stability of high-performance electronic monitoring and control systems.

Special emphasis is placed on the technological and regulatory challenges associated with the implementation of fundamentally new engineering solutions, composite materials, and nanostructured materials intended for environmentally oriented food manufacturing technologies and commercial food service applications, where regulatory approval represents a critical prerequisite for industrial implementation.

The article further discusses the opportunities created by the emergence of quantum computing technologies and equivalent ultra-high-performance computational platforms, whose processing capabilities substantially exceed those of conventional computing systems. These advances make it possible to introduce ecosystem-based infrastructure elements and advanced engineering tools that transform the conventional food process engineer's workplace into a Smart Food Process Engineering Workstation and support the development of Intelligent Food Manufacturing Environments. The proposed equipment, engineering solutions, digital ecosystem architecture, intelligent monitoring technologies, and integrated control methods are presented as innovative technological developments with significant practical potential for environmentally sustainable food manufacturing and food service industries, while also demonstrating substantial prospects for intellectual property protection through integrative and combinatorial patent strategies.

Keywords: *Ecosystem-based smart workstation equipment; ecosystem-based smart workstation equipment for food process engineers; real-time monitoring of the environmental safety level of food manufacturing processes; ecological smart workstation equipment for food process engineers and its innovative vortex-generation-based modifications; achievement of the ideal final result through the use of activated carbon-carbon fabrics and their innovative modifications; integrative modules for electronic systems, including laser diodes, with an intensive cooling system based on diamond-copper composite materials*

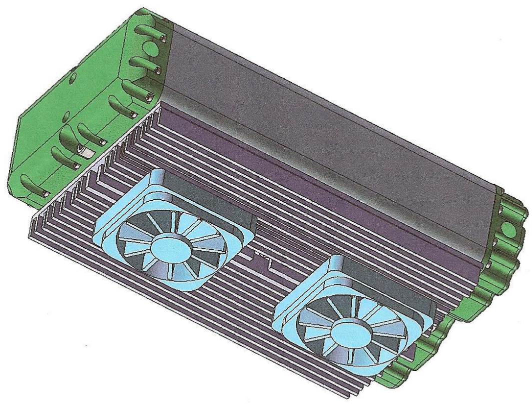
Introduction

In general, innovation is not an end in itself. The primary objective of the innovation process is to achieve an end result through the implementation of innovative ideas at a level that enables a qualitative improvement of all parameters of food manufacturing processes and their innovative modifications while preserving the continuity and compatibility of existing equipment, technologies, materials, and consumables.

The author of this publication aims to examine several fundamental relationships among these elements and to analyze the principal methodologies and engineering approaches for integrating innovative technologies, materials, and technical solutions into the existing framework of conventional food manufacturing processes. Particular attention is devoted to the interdependencies between established technological methods, engineering practices, production materials, and their innovative modifications.

Until relatively recently, when the innovation process was carried out primarily by specialists in food technologies and materials science who possessed limited experience in computer modeling, digital simulation, and process emulation, the implementation of new technologies was generally based on experimentally verified results obtained through laboratory testing, pilot studies, and practical investigations.

Figure 1. *Portable Air Purification System Utilizing Granulated Zeolite and Vortex Generation Technology*

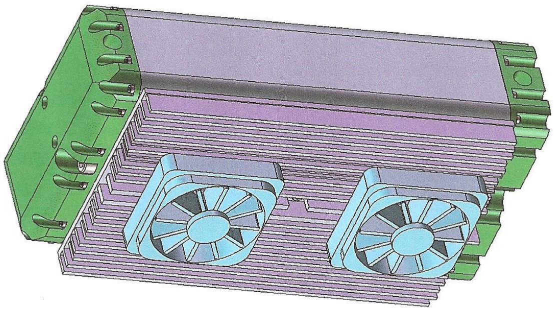


The field of technological innovation is generally characterized by a high degree of saturation with conventionally applied engineering solutions, technologies, and materials. Consequently, innovative modifications of all categories must be adapted to, and integrated with, existing technological processes, engineering practices, and material systems in order to ensure their successful implementation.

The specific requirements associated with the design, construction, logistics, renovation, and modernization of intelligent food manufacturing facilities, together with the development of their innovative ecosystem infrastructure components aimed at maximizing economic efficiency and ensuring the highest standards of environmental sustainability throughout both construction and operational phases, require fundamentally new approaches to the design, organization, and technical equipment of the Smart Food Process Engineering Workstation.

The application of advanced principles governing the design, construction, and operation of the infrastructure of intelligent industrial facilities and Smart Food Process Engineering Workstations plays a crucial role in the development of integrated regeneration and recirculation systems, including wastewater treatment and recycling technologies. These requirements necessitate the implementation of fundamentally new engineering concepts, structural solutions, and industrial design approaches capable of supporting environmentally sustainable, resource-efficient, and digitally integrated food manufacturing environments.

Figure 2. *Portable Air Purification System Utilizing Granulated Zeolite and Vortex Generation Technology*



Within infrastructure and fundamental engineering solutions, including auxiliary systems, properly coordinated and harmoniously integrated interactions among all system components are critical to the success of the innovation process. Such integration determines the effectiveness of innovative solutions in conjunction with the overall infrastructure, engineering architecture, industrial design, and specialized equipment of the production environment.

The specific standards, technical requirements, and regulatory provisions governing the development of an ecosystem-based infrastructure for intelligent industrial facilities, including the Smart Food Process Engineering Workstation, require that real-time monitoring, process control, and decision-support functions be incorporated into the system architecture. Particular consideration should also be given to partial energy supply through the integration of renewable energy sources, including solar power technologies.

Specialized integrated smart technological equipment intended for the manufacture of structural and infrastructure components of intelligent food manufacturing facilities, together with their conventional engineering counterparts represented by the Smart Food Process Engineering Workstation and its various configurations, requires an entirely new systems-engineering approach. Such an approach should ensure the achievement of the ideal final result while simultaneously maintaining full compliance with applicable technical standards, engineering regulations, and environmental and operational requirements.

Figure 3. *Aerodynamic Foam Generators with a Wide Range of Applications in the Smart Food Process Engineering Workstation*

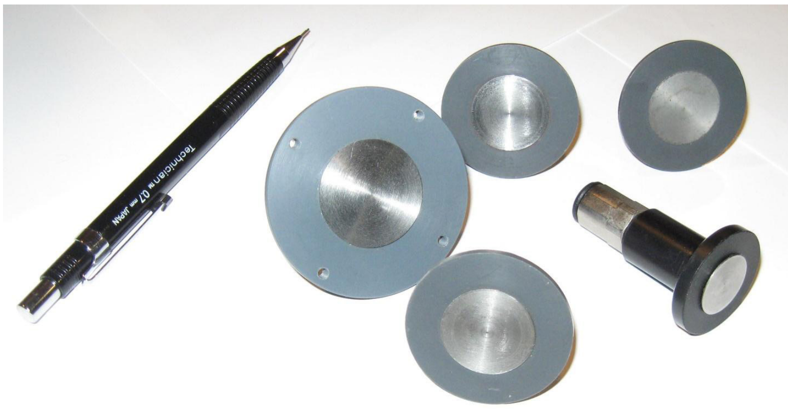


Figure 4. *Rear Housing of the Portable Air Purification System Utilizing Granulated Zeolite and Vortex Generation Technology*

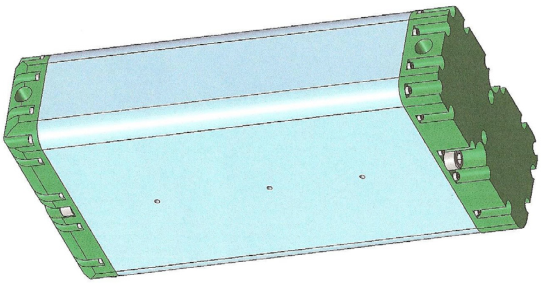
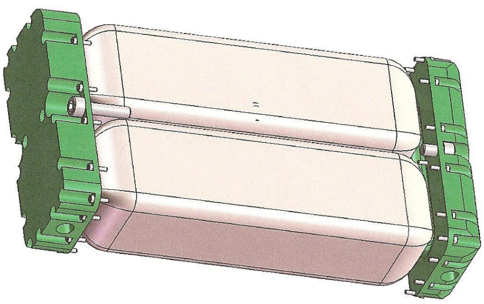


Figure 5. *Zeolite Capsules of the Portable Air Purification System Utilizing Granulated Zeolite and Vortex Generation Technology*



In general, innovation is not an end in itself. The central objective of the entire innovation process is to obtain a final result from the implementation of innovative ideas at a level that enables a qualitative improvement of all parameters of the food manufacturing process, while preserving the continuity of equipment, technologies, materials, and consumables.

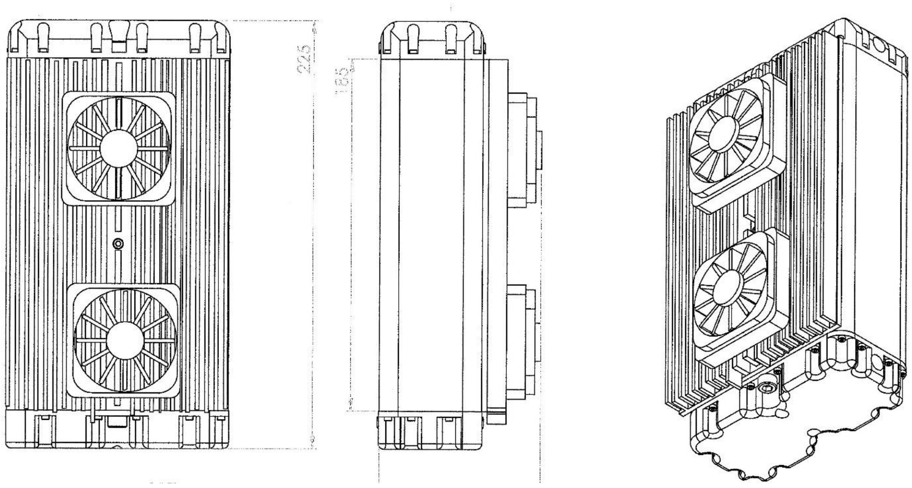
In principle, the author of this publication intends to examine certain actual interdependencies among these elements and to analyze the basic methods and schemes for adapting innovative solutions and materials within the structure of, and in relation to, traditionally used technologies, methods, and materials.

Until relatively recently, when the innovation process was largely conducted by specialists in conventional food technologies and materials who did not possess sufficient experience and skills in computer modeling and process simulation, implementation was carried out mainly on the basis of positive results obtained through testing and research.

For a considerable period of time, a dialogue was maintained, although not always successfully, between conservative specialists and innovators, and this dialogue did not always develop in favor of the innovators.

Practitioners remained in anticipation of solutions that could clearly demonstrate realistic and effective ways of implementing innovations without any significant disruption to the stability and balance of established technological processes.

Figure 6. *Assembly Drawings of the Portable Air Purification System Utilizing Granulated Zeolite and Vortex Generation Technology*



Modern engineering, advanced manufacturing technologies, and industrial design play a fundamental role in the development of structural systems and infrastructure for intelligent industrial facilities and their innovative counterparts created in accordance with projected technological trends and related engineering disciplines. These approaches enable the implementation of a complete conventional operating cycle, including, for example, composite fuel regeneration and recirculation processes, while adapting such engineering solutions to the classical principles of the Theory of Inventive Problem Solving (TRIZ) and the Algorithm for Inventive Problem Solving (ARIZ).

The concept of the Smart Food Process Engineering Workstation, together with the requirements of applicable technical standards and regulatory frameworks, establishes the fundamental engineering and software development principles governing the design and implementation of intelligent workstations for food process engineers. These requirements also extend to the workstation's integrated technological, analytical, and laboratory infrastructure, providing a unified ecosystem that supports intelligent process monitoring, environmental safety, production management, and engineering decision-making within modern food manufacturing environments.

To the credit of those advocating the innovative transformation of food manufacturing technologies, it should be recognized that recent years have witnessed the emergence of several comprehensive engineering solutions enabling the effective integration of innovative technologies into the practical conditions of modern food science, food manufacturing, and related industrial sectors.

The author of this publication considers comprehensive integrative approaches to be the most promising, particularly those presented in the scientific and technological publications of Liubov Skokova.

One of the principal characteristics distinguishing Liubov Skokova's engineering concepts and technological developments from comparable proposals is the extensive platform for experimental computer modeling that underpins her research. This capability is based on her broad and in-depth expertise in the fundamental principles and methodologies of systems engineering, combinatorial computer modeling, and digital simulation applied to interdisciplinary innovation processes, including those developed at the intersection of multiple fundamental scientific and engineering disciplines.

Figure 7. *Configuration of the Portable Air Purification System Utilizing Granulated Zeolite and Vortex Generation Technology. Cross-Sectional View Illustrating the Distribution of Granulated Zeolite within the System's Working Volume, Divided into Two Independent Sections. The Zeolite Granules Are Contained in Permeable Elastic Bags*

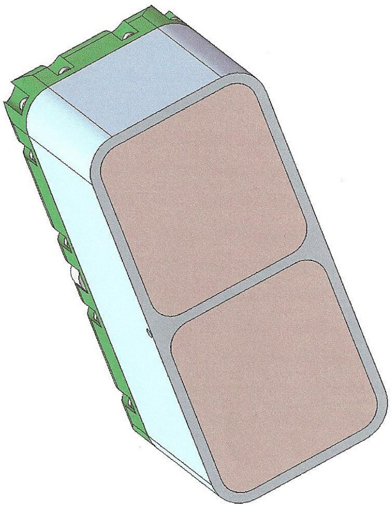
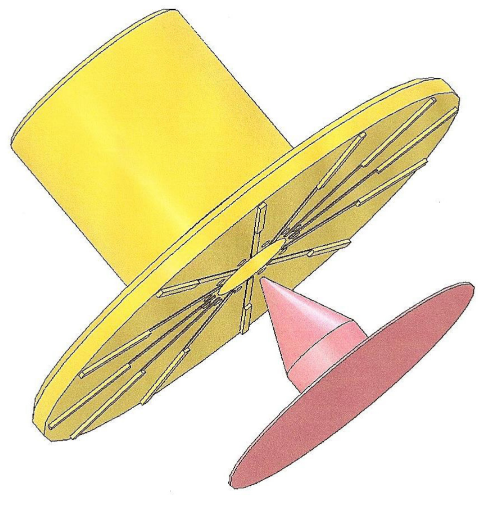


Figure 8. *The Figure Presents a Three-Dimensional Model of a Multifunctional Device Incorporating Several Operational Functions: a Foam Generator, a Vortex-Tube Generation System, and a Non-Contact Vacuum Gripping Device for Robotic Applications within the Equipment of a Smart Food Process Engineering Workstation*



An analysis of the innovative technologies presented throughout Liubov Skokova's scientific publications reveals a fundamentally important concept for addressing contemporary engineering challenges – namely, the combinatorial architecture of each engineering solution. This approach is based on the harmonious integration and mutual complementarity of conventional technologies and materials with innovative technologies and advanced materials, particularly composite materials.

Among Liubov Skokova's engineering concepts, the most significant contribution is the systematic integration and comprehensive adaptation of new materials and technological methods within the framework of established, validated manufacturing technologies and engineering practices. This methodology creates the conditions for the gradual transformation of the performance characteristics and functional capabilities of existing systems to a fundamentally new technological level.

The adoption of this engineering philosophy makes it possible to account for the future evolution of materials, structural designs, and manufacturing technologies, thereby enabling a gradual transition from flexible, permeable, three-dimensional porous systems and materials to solid materials possessing equivalent chemical compositions and functional characteristics while offering enhanced mechanical performance and durability.

The transformation of the fundamental principles governing the integrated design and manufacture of materials, structural components, and infrastructure for intelligent industrial facilities – including all systems associated with the infrastructure and equipment of the Smart Food Process Engineering Workstation – is directed toward the development of comprehensive, intelligent, flexible, multifunctional, and automated manufacturing environments. Such production systems are intended to generate innovative smart components and engineering assemblies while supporting integrated online regeneration technologies and advanced process-management systems assisted by modern computing platforms employing artificial intelligence (AI) and artificial neural networks (ANNs).

Comprehensive online, non-contact, and fully automated monitoring of environmental conditions, technological parameters, and operational processes associated with intelligent industrial installations and infrastructure components, performed in real time and, whenever possible, through remote supervisory control, represents one of the key functional requirements of the Smart Food Process Engineering Workstation. These monitoring systems continue to evolve toward increasingly sophisticated architectures in response to progressively more stringent regulatory standards, growing environmental challenges, and the expanding technical requirements applicable to intelligent food manufacturing facilities and smart food production environments.

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