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Conference Report

Abstracts of the 4th International Electronic Conference on Processes (ECP 2025) †

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Abstract

The 4th International Electronic Conference on Processes—Sustainable Process Design, Engineering, Control and Systems Innovation (ECP 2025) was hosted online from 20 to 22 October 2025. The event presented recent process/systems-related research in the fields of chemistry, biology, pharmaceuticals, nutraceuticals, materials, energy, environment, food, and engineering. The main topics and sessions of the conference were as follows: Environmental and Green Processes; Chemical Processes and Systems; Food Process Engineering; Process Control and Monitoring; Materials Manufacturing and Sustainable Packaging; Pharmaceutical Processing and Particle Processes.

Keywords: pharmaceuticals; new formulation techniques; nutraceuticals; cosmetics; new bio-materials and sustainable packaging; alternative energy sources; new recycling and upcycling processes; new techniques for polluted water treatments

1. Conference Introduction

Conference Sessions

- Session 1. Environmental and Green Processes

Session Chairs:

Prof. Dr. Young-Cheol Chang, Division of Sustainable and Environmental Engineering, Muroran Institute of Technology, Hokkaido, Japan;

Dr. Omprakash Sarkar, Department of Civil, Environmental, and Natural Resources Engineering, Luleå University of Technology, Luleå, Sweden.

- Session 2. Chemical Processes and Systems

Session Chair:

Professor Blaž Likozar, Department of Catalysis and Chemical Reaction Engineering, National Institute of Chemistry, Ljubljana, Slovenia.

- Session 3. Food Process Engineering

Session Chair:

Prof. Dr. Dariusz Dziki, Department of Thermal Technology and Food Process Engineering, University of Life Sciences in Lublin, Lublin, Poland.

- Session 4. Process Control and Monitoring

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Session Chairs:

Dr. Ravendra Singh, Department of Chemical and Biochemical Engineering, Rutgers University, 98 Brett Road, Piscataway, NJ, USA;

Dr. Jie Zhang, School of Engineering, Merz Court, Newcastle University, Newcastle upon Tyne NE1 7RU, UK.

- Session 5. Materials Manufacturing and Sustainable Packaging

Session Chairs:

Dr. Maria Josè Lo Faro, Department of Physics and Astronomy, University of Catania, Catania, Italy;

Dr. Adina Magdalena Musuc, Department of Chemical Kinetics, Institute of Physical Chemistry—Ilie Murgulescu, Romanian Academy, Bucharest, Romania.

- Session 6. Pharmaceutical Processing and Particle Processes

Session Chair:

Dr. Paolo Trucillo, Department of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, Piazzale V. Tecchio, 80, 80125 Naples, Italy.

2. Environmental and Green Processes

2.1. A Leptolyngbya-Dominated Consortium for the Optimized Biological Treatment of Mixed Agro-Industrial Effluents

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Wastewater streams are a low-cost nutrient source for cultivating microalgae and cyanobacteria. However, single streams often exhibit imbalanced nutrient profiles, insufficient to support optimal microbial growth. Mixing streams with complementary physicochemical properties can balance nutrients and eliminate the need for external supplementation. Optimizing the mixing ratio is essential to achieve favorable carbon-to-nitrogen (C:N) ratios, enhance biomass and biocompound production, and improve culture conditions such as turbidity and pH. This study aimed to identify the optimal mixing ratio of two agro-industrial wastewaters, second cheese whey (SCW) and poultry wastewater (PW), for the cultivation of a *Leptolyngbya*-dominated consortium. SCW had higher organic and lower inorganic nutrient content than PW. Increasing the SCW proportion raised the C:N ratio and induced N and P limitations, conditions known to promote lipid accumulation. Four SCW:PW ratios (50:50%, 60:40%, 70:30% and 85:15%) were examined based on the initial dissolved chemical oxygen demand (d-COD) concentration of 3000 mg L^{-1}. The 60:40% and 70:30% SCW:PW ratios yielded the highest biomass productivities (276.6 and 268.3 mg L^{-1} $d^{-1,}$ respectively), while the 50:50% resulted in the lowest productivity (174.6 mg L^{-1} d^{-1}), likely due to turbidity. A progressive enhancement in pollutant removal efficiency was observed with increasing SCW proportions. The 70:30% ratio achieved the highest d-COD (89.2%), total nitrogen (64%) and PO_4^{3-}-P (60%) removal, as well as the highest lipid content (14.0% d.w.). This ratio was identified as optimal. The 85:15% ratio also demonstrated enhanced lipid content (11.9% d.w.), attributed to the reduced turbidity and consequent improved light penetration, favoring the proliferation of lipid-producing autotrophic microorganisms within the consortium.

2.2. A Bibliometric Review of Oil Palm Residues for Thermochemical Bioenergy Conversion in West Africa

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Agricultural biomass residues, such as palm kernel shells (PKSS), empty fruit bunches (EFBS), and palm kernel fibers, are produced in substantial quantities from oil palm processing, particularly in tropical regions like West Africa. These residues constitute a significant yet underutilized renewable resource for sustainable bioenergy production. This systematic review seeks to assess the intellectual structure of knowledge related to the bioenergy potential and thermochemical conversion of these residues. A structured literature search was conducted using the Scopus database, focusing on peer-reviewed studies published between 2020 and 2024, adhering to PRISMA guidelines. This study reports the proximate and ultimate analysis, calorific value, moisture and ash content, and combustion and pyrolysis.

VOS viewer software was utilized for bibliometric analysis to identify research trends and knowledge clusters. The mapping of keyword co-occurrences demonstrated strong thematic connections among "palm kernel shell," "pyrolysis," "heating value," and "bioenergy," thereby highlighting key research areas. The frequency of research currently attracting the most attention in this field is also presented to consolidate the current knowledge on oil palm biomass residues and propose an actionable model for optimizing their use in domestic and industrial thermal energy systems. It also highlights critical gaps and opportunities for further research in developing localized, scalable biofuel technologies to accelerate the clean energy transition in biomass-rich developing regions.

2.3. A Systematic Review of LCA and OpenLCA Applications for Carbon Emission Mapping in Processes

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This paper examines how Life Cycle Assessment (LCA), particularly when conducted using OpenLCA software, is being applied to measure and manage carbon emissions in various processes. With many industrial and operational processes contributing significantly to global greenhouse gas emissions, tools like LCA have become essential to track where emissions come from and how to reduce them across entire production and service chains. OpenLCA, in particular, has emerged as a widely used platform due to its open-source nature, adaptability, and support for a variety of global databases. These features make it accessible not only to researchers but also to industries and policymakers aiming to design greener and more sustainable process operations. This study systematically reviews 36 peer-reviewed papers published between 2015 and 2025. The selected studies cover a broad range of applications, including last-mile delivery, multimodal freight transport, warehousing operations, and integrated supply chains. The review process followed PRISMA guidelines to ensure transparency and a structured selection of relevant literature. The findings highlight recurring low-carbon strategies, such as the adoption of electric vehicles, optimization of routing systems, and modal shifts to more sustainable transport options. Despite these innovations, the review also identifies common limitations. These include the lack of region-specific emission data, inconsistencies in defining system boundaries, and minimal attention to uncertainty analysis within LCA models. In conclusion, the review reinforces the importance of LCA and OpenLCA specifically in guiding various

process sectors toward more sustainable practices. However, to make these tools even more effective, there is a need for higher-quality datasets, harmonized methodologies, and a stronger focus on context-specific applications in both developed and developing regions.

2.4. A Comprehensive Examination of Catalysts Enhancing Effectiveness and Innovation in Thermal Reactions

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Catalysts are indispensable in many industries, optimizing thermal reactions and boosting productivity and creativity. This article offers a comprehensive analysis of catalysts used in thermal processes, examining their critical role in enhancing chemical reactions at high temperatures. The paper starts with an overview of the research context, defining catalysts and underscoring their importance in enabling efficient chemical transformations by lowering activation energy. It explores the two primary types of catalysts—heterogeneous and homogeneous—detailing their respective mechanisms, uses, and applications.

Through an in-depth examination of catalytic processes, the article explains complex phenomena like adsorption, desorption, and intermediate generation that direct reactions on catalyst surfaces. These mechanisms are essential for understanding how catalysts influence thermal reactions and contribute to improved process efficiency. The review highlights the crucial role of catalysts in diverse industries, including petrochemicals, chemical synthesis, energy production, and environmental remediation.

The article also delves into advanced characterization methods used to study catalysts, as well as challenges in catalyst design, including issues like stability and selectivity. Furthermore, it looks at future approaches to catalyst development, aiming to address current limitations and explore new possibilities for enhancing thermal processes. Through case studies, the practical applications of catalysts are highlighted, demonstrating their transformative impact on industry.

In conclusion, the paper emphasizes the significant potential of catalysts to revolutionize thermal processes, calling for continued research to push the boundaries of innovation. Catalysts, as agents of progress, hold the key to advancing thermal reactions to new levels of efficiency and creativity.

2.5. A Novel Circular Waste-to-Energy Pathway via Cascading Valorization of Spent Coffee Grounds Through Non-Catalytic Supercritical Transesterification of Pyrolytic Oil for Liquid Hydrocarbon

Elmer Jann Bantilan [1], Joana Batistil [1], Bernice Ann Calcabin [1], Ephriem Organo [1], Neome Mitzi Ramirez [1], Rich Jhon Paul Latiza [1,2], Jayson Binay [1], Reibelle Raguindin [1,3] and Rugi Vicente Rubi [1,2]

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The ever-growing global consumption of coffee generates millions of tons of spent coffee grounds (SCGs) annually, posing a significant waste disposal problem. While some SCGs find use in composting or biogas production, a large portion remains underutilized. This study introduces a novel circular waste-to-energy pathway to tackle this challenge. Our

proposed technology employs a cascading valorization approach, utilizing non-catalytic supercritical transesterification of pyrolytic oil derived from SCGs for liquid hydrocarbon production. The process begins with pyrolysis, which converts SCGs into pyrolytic oil. This oil is then upgraded via supercritical transesterification with methanol. Experiments were conducted using a 1:6 oil-to-methanol ratio at precisely controlled conditions of 239.4 °C and 1200 psi for 20 min. This optimized process yielded an impressive 96% of valuable liquid hydrocarbons. The resulting product exhibited highly favorable characteristics, including a density of 755.7 kg/m^3, a viscosity of 0.7297 mm^2/s, and a high heating value (HHV) of 48.86 MJ/kg. These properties are remarkably comparable to conventional biofuels and standard fossil fuels, demonstrating the product's potential as a viable energy source. These compelling results unequivocally demonstrate that non-catalytic supercritical transesterification effectively upgrades SCG-derived pyrolytic oil into valuable liquid hydrocarbons. This innovative approach offers a sustainable solution for SCG waste management, significantly contributes to a circular bioeconomy, and presents a promising alternative for renewable fuel production, thereby potentially reducing global reliance on fossil fuels.

2.6. Adsorption of Methylene Blue Dye Using Mango Leaf Powder

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This research investigates the adsorption of methylene blue dye. Methylene blue is a common cationic dye used in various industries, and its presence in wastewater poses significant environmental and health concerns. Traditional methods for dye removal can be expensive and generate secondary pollutants. Mango leaf powder proves to be a cost-effective and environmentally friendly adsorbent for the removal of methylene blue (MB) dye from aqueous solutions. Characterization was performed through Scanning Electron Microscopy (SEM) for the morphology of the mango leaf powder; Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD) for the crystallinity of the mango leaf powder; and Thermogravimetric Analysis (TGA) for the thermal stability of the mango leaf powder. Batch adsorption experiments were conducted to evaluate the efficiency of mango leaf powder in removing methylene blue from aqueous solutions. The study employed both Langmuir and Freundlich isotherms to analyze the adsorption data, revealing a higher correlation coefficient for the Freundlich model (R^2 = 0.932) compared to the Langmuir model (R^2 = 0.8864). Kinetic studies indicated that the pseudo-second-order model provided a better fit for the adsorption process (R^2 = 0.8288). Thermodynamic parameters were calculated, showing a Gibbs free energy change (ΔG) of -0.364×10^{-3} kJ/mol, an enthalpy change (ΔH) of -0.521×10^{-3} kJ/mol, and an entropy change (ΔS) of 2.233 J/mol·K, indicating that the adsorption process is spontaneous and exothermic in nature. Furthermore, a reusability study demonstrated that mango leaf powder can be effectively reused across three cycles without significant loss in adsorption capacity, affirming its potential as a sustainable biosorbent for wastewater treatment applications.

2.7. Advanced Oxidation Process for the Decontamination of Tetracycline from Wastewater Using Immobilized Magnetite

Vincy Antoney [1], Gayathri Padinchare Veettil [2], Divya Nair [3], Telsa T. [1], Sreelakshmi M.G [1], Sneha V.S [1] and Thara Surendran [1]

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Pollution due to pharmaceutical contaminants has emerged as a significant ecological issue, affecting water quality, marine ecosystems, and humans across the globe. Due to the increasing concern over pharmaceutical pollutants, effective and sustainable treatment methods are of critical need. This study investigates the solar-assisted photocatalytic degradation of tetracycline hydrochloride (TCT), a persistent pharmaceutical contaminant in aqueous systems, using magnetite nanoparticles as immobilized catalyst. The catalyst was synthesized using a precipitation method. Key operational variables influencing degradation efficiency were systematically analyzed. The degradation followed pseudo-first-order kinetics with approximately 48% TCT removal within 30 min and up to 99% within 120 min under sunlight exposure. The introduction of a Fenton reagent notably enhanced the photocatalytic performance. The synthesized catalyst was characterized using various techniques. The process also contributed to a reduction in chemical oxygen demand (COD), and by using liquid chromatography–mass spectrometry (LC-MS), the intermediates during the degradation were identified. The catalyst reusability tests indicated minimal loss in activity over successive cycles. These findings highlight the viability of integrating solar energy with immobilized magnetite nanocatalysts for sustainable wastewater treatment, offering an effective method for removing antibiotic residues and promoting water reuse. Future research should focus on exploring new magnetite composites and the potential for integrating this technology with real-world applications.

2.8. Advanced Oxidation Processes in Microreactors for Hospital Wastewater Treatment

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Microreactors have emerged as effective platforms for photocatalytic advanced oxidation processes targeting the removal of persistent emerging contaminants, such as steroid hormones, from hospital wastewater. Steroidal endocrine-disrupting compounds, particularly estrogens and progestins, are commonly present in hospital effluents and are known for their resistance to conventional treatment technologies. Photocatalytic systems based on microreactors offer several advantages over traditional batch photoreactors, including higher surface-area-to-volume ratios, enhanced mass transfer, and reduced diffusion limitations. The continuous microflow facilitates uniform photon distribution and accelerates reaction kinetics. By enabling efficient fluid transport under laminar flow through mi-

crochannels, microreactor technology significantly mitigates the mass transfer constraints often associated with catalyst immobilization, owing to the shortened diffusion path from the aqueous phase to the photocatalyst surface. In this study, the degradation efficiency of two representative steroidal hormones, norethindrone and oestrogen, was evaluated using a continuous-flow microreactor system with TiO_2 immobilized and irradiated by UVA-LED light. The key optimized process variables were pH, temperature, hydrogen peroxide concentration, and volumetric flow rate. The reaction system was equipped with piston-driven injection pumps, a Peltier thermal control module, pressure regulation, and online monitoring 1H NMR.

Photocatalytic degradation efficiency was assessed through spectral analysis using 1H NMR, IR, and UV–Vis spectroscopy. The optimal operational conditions for norethindrone degradation (79.3%) were pH 10, 20 °C, 10 mL/min, and 2 ppm H_2O_2. Under the same conditions, oestrogen degradation reached 68%. These results highlight the potential of integrating microreactor-based photocatalysis into hospital wastewater treatment frameworks as a sustainable and efficient solution to eliminate recalcitrant endocrine-disrupting contaminants, thereby contributing to improved environmental and public health protection.

2.9. Aluminium-Based Metal–Organic Framework 53 Coordinated with Manganese for Carbon Capture

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Advanced adsorbents for carbon capture applications are becoming more and more popular due to the pressing demand for effective materials to address rising carbon dioxide (CO_2) impacts. This study investigates the development and characterization of a bimetallic aluminium/manganese-based metal–organic framework for carbon capture. The framework was designed with varying ratios of manganese, with various reaction times and temperatures. Comprehensive characterization included Brunauer–Emmett–Teller (BET) surface area analysis, scanning electron microscopy (SEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), X-ray fluorescence (XRF), and thermogravimetric analysis (TGA). The BET measurements are expected to predict textural properties that reveal higher surface areas for samples under moderate conditions and lower Mn/Al ratios, while SEM analysis is expected to reveal morphological analysis, well-defined MOF crystals with increasing Mn/Al altering particle size and surface texture; excessive manganese might lead to aggregation. XRD is expected to confirm MOF-53's crystalline structure and successful manganese integration, while XRF is expected to present a high concentration of Al and Mn oxides. The FTIR spectra should display characteristic bands for the framework and the organic linker, with possible shifts or the broadening of Al–O and Mn–O bands at higher Mn concentrations. TGA is expected to show good thermal stability at temperatures up to 250 °C but may show reduced stability at high Mn/Al ratios. Al/Mn-MOF-53 synthesized at 100 °C for 48 h with a Mn/Al ratio of 0.2 is expected to have the highest CO_2 uptake through sorption measurements. Overall, the characterization results are anticipated to evidently demonstrate the influence of manganese content and process conditions on framework integrity and performance, confirming that lower manganese incorporation and moderate synthesis parameters yield materials best suited for carbon capture due to their stability, maximized surface area, and accessible pore structure.

2.10. Accurate Extraction of Photovoltaic Parameters by Simulated Annealing Optimization: A Robust Approach to Model Fitting Enhancement

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Accurate photovoltaic (PV) cell modeling is critical to the analysis, diagnostics, and design of solar energy systems. At its center is the extraction of unknown parameters of the single-diode or double-diode models, which are nonlinear in nature and have high sensitivity to initial guesses. In this paper, we propose an efficient and powerful optimization method using Simulated Annealing (SA) for PV parameter extraction at standard test conditions. SA, a probabilistic metaheuristic inspired by the annealing process in metallurgy, is employed in minimizing the deviation of the experimental current–voltage (I–V) data from the model-generated curves.

The algorithm is tested on benchmark PV modules with real I-V characteristics, and its performance is verified in terms of Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and R^2 score. A comparison with other optimization techniques such as Particle Swarm Optimization (PSO) and Genetic Algorithms (GAs) confirms the effectiveness and reliability of the SA-based approach. The results show that the SA algorithm leads to fast convergence, avoids local minima, and provides highly accurate parameter estimates with very good agreement with the experimental data.

This research demonstrates the potential of SA optimization as a flexible and reliable approach to PV modeling, especially for researchers and engineers who need precision and strength in solar energy system simulations.

2.11. Advancing Sustainable Wastewater Reuse with Electrochemical Dynamic Membranes: The eSFDMBR Approach

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The evolution of wastewater treatment technologies is increasingly oriented toward hybrid solutions that combine treatment efficiency, economic sustainability, and operational simplicity. In this context, this study proposes an innovative approach based on an integrated bioreactor called eSFDMBR (electro Self-Forming Dynamic Membrane Bioreactor), which combines self-forming dynamic membranes (SFDMs) with electrochemical processes.

The system treats real wastewater of civil origin with variable loads. At its core is a membrane made of a highly porous fibrous support, on which a filtering layer forms naturally through particle deposition. Internal electrodes generate redox reactions that enhance pollutant removal, inhibit biofilm formation, and limit fouling.

Results showed performance superior to traditional MBR (Membrane Bioreactor) systems. The removal efficiencies obtained in this innovative system were higher by more than four percentage points for COD (Chemical Oxygen Demand) removal, by approximately forty percentage points for NH_4-N (Ammonium Nitrogen) removal, and by more than fifty percentage points for PO_4-P (Orthophosphate) removal.

The system maintained stability despite variations in load and temperature, demonstrating remarkable operational resilience.

Fouling control, one of the main limitations of MBRs, was effectively addressed through electrochemical action, which significantly reduced the presence of EPSs (Extracellular Polymeric Substances) and SMPs (Soluble Microbial Products). This ensured stable transmembrane pressure and reduced the need for cleaning interventions.

From an economic and management perspective, the use of low-cost membrane materials, combined with the process efficiency, leads to lower costs compared to conventional membrane systems. Moreover, the reactor's simple design and operational flexibility make it suitable for decentralized contexts.

In summary, the eSFDMBR represents a promising solution for more sustainable and efficient wastewater treatment.

2.12. Alkaline Hydrolysis of Tetra Pak Waste: A Green Process for Hydrogen Production and a Cement Hydration Catalyst

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This study introduces a clean, low-impact recycling method for Tetra Pak waste (TPW), demonstrating how green chemistry principles can transform complex post-consumer materials into valuable resources. The multilayer composition of TPW, primarily aluminum and polyethylene, poses significant challenges for conventional recycling due to its resistant structure. To overcome this, we developed a sustainable aqueous alkaline hydrolysis process that efficiently separated these layers under mild conditions, eliminating the need for toxic solvents or high energy consumption. A key advantage is the simultaneous generation of green hydrogen gas, a clean, renewable energy carrier produced by the reaction between aluminum and sodium hydroxide. Alongside hydrogen production, the process yields a porous, lettuce-like sodium aluminate byproduct. Rather than disposing of this solid, we repurpose it as an environmentally friendly additive in cement systems. When incorporated into Portland cement, it significantly accelerates the hydration process, dramatically reducing the initial setting time from 285 min to just 87 min. This catalytic effect was verified using Differential Scanning Calorimetry (DSC) and temperature evolution analysis. By addressing multiple environmental challenges, waste valorization, renewable energy generation, and enhanced construction materials, this integrated approach exemplifies green chemistry and circular economy principles. It provides a scalable, eco-friendly solution for sustainable industrial development and responsible resource management.

2.13. An Efficient Energy Management System Based on Fuzzy Logic Control in DC Microgrids

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The increasing global adoption of renewable energy technologies, including photovoltaics, wind power, tidal energy, and fuel cells, is primarily driven by the imperative to address pressing environmental and resource challenges. These include the finite nature of fossil fuels, particularly petroleum depletion, and the escalating threat of anthropogenic climate change. The inherent variability and intermittency of individual renewable energy sources, primarily driven by unpredictable meteorological conditions, present significant challenges to reliable energy supply. Consequently, the integration of an energy storage system is increasingly being favored to ensure consistent power delivery and minimize disruptions for end consumers.

This strategy effectively mitigates the limitations of any single renewable energy source, enhancing overall system resilience and reliability; however, the complex op-

erational dynamics of microgrids present considerable challenges to achieving optimal performance and resource utilization.

In this paper, the application of fuzzy logic control as a strategy for optimizing energy management within DC microgrids including a photovoltaic array and battery storage system is discussed. Fuzzy logic control is particularly well suited for this application due to its flexibility, robustness when facing disturbances, and inherent adaptability to nonlinear and uncertain systems, a crucial advantage when addressing the significant variability and intermittency associated with renewable energy sources.

Simulations using MATLAB/Simulink are used to evaluate the performance and efficacy of the proposed fuzzy logic-based energy management system within DC microgrid environments. This study significantly contributes to the field by empirically demonstrating the viability of DC microgrids as robust and efficient energy solutions.

2.14. Analysis of Salvinia Molesta and Water Hyacinth Phytoremediation Processes Totreat Effluent Using Response Surface Methodology

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Recent research trends show interest inovercoming the limitations of wastewater treatment systems and technologies. More researchers are investigating ecologically friendly, low-cost, and low-maintenance alternatives. More focus is being placed on environmentally friendly and sustainable treatment techniques as a result of the growing population and increasing industrialization, which have increased the pollution load on receiving water bodies from both point and non-point sources. Because of its effectiveness, affordability, and sustainability, the phytoremediation process is among the greatest ways to remediate wastewater. The system's advantages and response surface methodology (RSM) are used in this work to make predictions. This process is important for enhancing the efficiency of pollutant removal from wastewater. Phytoremediation uses plants to absorb, degrade, or stabilize contaminants, offering a sustainable and low-cost solution. RSM provides a powerful statistical tool to optimize key operational parameters, identify significant factors, and model the treatment process accurately. Two different plants were placed in phytoremediation system tanks to treat wastewater treatment plant's effluent. *Water hyacinth* and *Salvinia molesta* were planted in separate tanks and observed concurrently. The pH and hydraulic retention time (HRT) of the tanks were varied during operation. The results revealed that the removal efficiency of chemical oxygen demand, total dissolved solids, total nitrogen, and turbidity were in the range of 51.84–79% for *Salvinia molesta* with pH 5, and 52.12–83% with pH 7. *Water hyacinth* recorded lower performances of 13.56–48.81% and 5.29–44.87%, respectively. Accurate predictions were made from the analysis of phytoremediation treatment of wastewater utilizing the response surface approach. Integrating RSM with phytoremediation improves the effectiveness and predictability of effluent treatment.

2.15. Application of Raw Agro-Waste Materials in Methylene Blue Dye Adsorption from Wastewater

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The large-scale production of various synthetic dyes has significantly contributed to the discharge of large volumes of wastewater into the environment. It is estimated that approximately 105,000 tons of dyes from the textile industry are released annually, severely compromising water quality [1]. In this context, the present study evaluates the adsorption potential of agricultural and timber residues—including *Tectona grandis* sawdust, baobab sawdust, coconut shells, cork bark, almond shells, and olive pits—for the removal of methylene blue (MB) from aqueous solutions. All materials were used without prior thermal treatment. Kinetic experiments were carried out at 298 K and pH 6, using 25.0 mg of adsorbent added to 25.0 mL of MB solution (20 mg L^{-1}), agitated at 20 rpm for up to 168 h. Adsorption isotherms were obtained using MB concentrations ranging from 0 to 250 mg L^{-1}, with agitation under the same conditions for 24 h. The influence of pH (3–11) was assessed by adjusting the pH with 0.1 mol L^{-1} HCl or NaOH and following the same adsorption procedure. The natural adsorbents demonstrated good performance in removing methylene blue from aqueous solutions. Among the tested agricultural wastes, coconut shells exhibited the highest MB removal capacity, reaching a maximum of 106 mg g^{-1} at 298 K and pH 6. These findings support the use of agricultural and timber sector residues as efficient and sustainable alternatives to conventional materials such as activated carbons. This approach aligns with circular economy principles, promoting waste valorization and reducing environmental impacts.

2.16. Assessing Optimal Green Hydrogen Strategy for an Inland Refinery

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The European Union aims for carbon neutrality by 2050. To achieve this goal, environmental regulations are being continuously introduced, with the latest Renewable Energy Directive (RED III) set to take effect in 2030. Notably, RED III specifies a minimum 5.5% share of biofuels and a 1% share of renewable fuels of non-biological origin (RFNBO) in the transportation sector. Hydrogen is a crucial component in refineries, and while it is currently produced mainly through reforming processes, they are to be partially replaced with RFNBO to comply with the RED III targets.

This work analyzes various methods to achieve RED III targets, i.e., RFNBO production directly in the refinery or its import in the form of green ammonia to be decomposed in the refinery, biomethane sourced to meet biofuel targets, and low-carbon hydrogen produced via thermal pyrolysis of natural gas. Strategic pathways were compared using Multi-Criteria Decision Analysis (MCDA), evaluating environmental, economic, technological, and implementation criteria to identify viable strategies to integrate renewable fuel solutions into refinery operations. Without predefined criteria preferences, steam biomethane reforming ranks highest in over 50% of consistent preference combinations, primarily due to its cost advantage. Considering environmental or technological preferences, electrolysis is favored due to its zero-emission profile and its ability to produce pure hydrogen at elevated pressures. Under a fixed priority order (economic > technological > implementation > environmental), biomethane reforming remains the top-ranked strategy. However, MCDA results are sensitive to external conditions. If changes in either renewable electricity prices or methane-based gas costs occur, electrolysis can outperform other options in the ranking. Ultimately, the corporate strategy must consider not only techno-economic aspects but also European regulations and market dynamics, which necessitates long-term planning to ensure company's competitiveness.

2.17. Assessing Electrocoagulation (Al and Fe Electrodes) and the Electro-Fenton Process for Landfill Leachate Membrane Concentrate Treatment

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In compliance with stringent standards for wastewater disposal, advanced processes have been implemented in several landfill leachate treatment plants (LTPs). Among these, membrane-based technologies have been adopted to remove contaminants beyond the capabilities of conventional methods. However, managing landfill leachate membrane concentrate (LLMC), the residual stream from membrane filtration, is a challenge for landfill operators. LLMC can comprise up to 50% of the incoming leachate, making its management a critical aspect of LTP operations. This study investigates the application of electrocoagulation (EC), using aluminum (Al) and iron (Fe) electrodes, as well as the electro-Fenton (EF) process, for LLMC treatment. EC tests were conducted using a laboratory-scale apparatus. In each trial, Al and Fe plate electrodes (15 $\times$ 3 $\times$ 2 cm) were connected in parallel, with a fixed inter-electrode distance of 30 mm. Treatment performance was assessed based on the true color, absorbance at 254 nm (Abs254), and dissolved organic carbon (DOC) removal. Abs254 was measured using a Shimadzu UV-1800 spectrophotometer (Method 5910-B). True color (Method 2120-C) and the chemical oxygen demand (COD; Method 5310-C) were determined according to the APHA (2017) standard methods, using a Hach DR2800 portable spectrophotometer for true color and a Shimadzu TOC-V analyzer for the COD, respectively. Before analysis, samples were filtered through 0.45 µm cellulose membrane filters. With the Al electrodes (pH = 9, 300–600 mA, 30 min), removal efficiencies of 18.1 $\pm$ 2.8% for color, 14.6 $\pm$ 1.9% for Abs254, and 24.3 $\pm$ 6.7% for DOC were achieved. Although the Fe electrodes yielded slightly better results, the overall performance remained below the levels reported in previous studies. Consequently, the treatability assessment was extended to include the electro-Fenton technique. Electrochemical advanced oxidation processes were evaluated by varying the LLMC's pH (3.0–5.0) and hydrogen peroxide (H_2O_2) concentrations (0–1000 ppm). These results are detailed in the extended abstract. Future research will focus on the economic feasibility of EC and electrochemical oxidation methods, considering factors such as the energy and electrode consumption and reagent requirements.

2.18. Biodiesel Production from Microalgae Using Ionic Liquid as Solvent

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Biodiesel is a type of renewable, biodegradable, non-toxic, and eco-friendly fuel which has been considered one of the best alternative resources to fossil fuels. Nowadays, one of the most promising substitute sources of biodiesel is considered to be microalgae. It offers several advantages over traditional crops, such as a high lipid content, rapid growth rate, greater photosynthetic efficiency, bio-remediation potential, and versatile growing conditions. This research focuses on the integration of ionic liquids into the process of biodiesel production from microalgae, which holds the promise of overcoming some of the limitations associated with the conventional methods.

This work focuses on the production of biodiesel from Nannochloropsis sp. microalgae. This study compares the effectiveness of conventional methods such as Soxhlet extraction and the Bligh and Dyer method for lipid extraction. The Bligh and Dyer method exhibited a higher lipid yield compared with that from Soxhlet extraction. Sonication parameters (sample volume, time, and power rate) were optimized to maximize the lipid yield. It further investigates the use of ionic liquids for lipid extraction from microalgae. Two ionic liquids, 1-(4 sulphonic acid) butyl-3-Methyl imidazolium hydrogen sulphate and 1-(4 sulphonic acid) butyl pyridinium hydrogen sulphate, were synthesized and characterized using FTIR, NMR, and TGA. As compared to the conventional methods, extraction using ionic liquids showed greater lipid efficiency. Biodiesel was produced through the transesterification of algal oil. FTIR was used to analyze the presence of lipids and esters in biodiesel. The produced biodiesel, with significant properties, meets the terms of the ASTM specifications (pH, density, acid value, free fatty acid, iodine value, and calorific value), indicating its suitability as biofuel.

2.19. Biotreatment of Second Cheese Whey in Pilot-Scale Photobioreactors Using Cyanobacteria-Based Consortia for Lipid Production

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Second cheese whey (SCW), a by-product generated after the production of cottage cheese, remains a highly polluted effluent due to its high organic and nutrient load. Despite its environmental impact, the biotreatment of SCW using microalgae/cyanobacteria has been limited, with even fewer studies involving pilot-scale photobioreactors. In this study, unsterilized SCW was treated employing a *Leptolyngbya*-based culture in two pilot-scale systems: a suspended growth system (SCW-S) and an attached growth system (SCW-A), both operated in 9 L tubular photobioreactors. For the attached system, fishing lines equipped with plastic biofilm carriers served as support material for microbial attachment. *Leptolyngbya* sp. is known to increase lipid content at C:N ratios of ≈45; thus, SCW was studied under these conditions, with an initial d-COD of about 2000 mg L^{-1}. The highest total biomass productivity was observed in SCW-A system, reaching 346.7 mg L^{-1} d^{-1}. Both systems achieved high effectiveness in pollutant removal (d-COD: 94.5–99.9%, TN: 89.0–96.5%, $NO_3{}^-$-N: 87.0–93.3%, $PO_4{}^{3-}$: 98.8–93.4%), while lipid contents were 16.1 and 15.1% d.w. for SCW-S and SCW-A, respectively. SCW-A proved highly effective, achieving almost complete d-COD (99.9%) and TN (96.5%) removal. Lipid analysis revealed increased saturation of fatty acids in the SCW-A, representing 74.6% of total fatty acids. The attached system was also applied to synthetic chemical medium (CM-A) to evaluate lipid production potential. The CM-A recorded lower biomass productivity (142.8 mg L^{-1} d^{-1}) and lipid content (12.0% d.w.), suggesting SCW's indigenous microbiota enhanced growth and lipid production. In conclusion, SCW is an effective feedstock for lipid-rich biomass production with *Leptolyngbya*, yielding saturated lipids suitable for biofuels.

2.20. Carbonisation and Characterisation of Charcoal Produced from Combretum malabaricum, Mimosa pigra, and Ipomoea carnea

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Globally, invasive alien species (IAS) present substantial socio-economic and environmental challenges, typically forming dense thickets and stands, which are largely accessible, unexploited, and underutilised sources of biomass. Therefore, this study examines the bioenergy potential of three IAS with woody stems, Combretum malabaricum (CM), Mimosa pigra (MP), and Ipomoea carnea (IC), as sustainable raw materials for charcoal production via carbonisation. It also examines the physico-chemical and energy properties of the resulting charcoals, thus presenting a sustainable valorisation approach. Carbonisation was conducted in a muffle furnace at a temperature of 600 °C and with a 30-min residence time, followed by charcoal characterisation. Next, the charcoals were characterised to gravimetrically and computationally determine their mass yield (MY), higher heating value (HHV), and energy yield (EY). The results revealed that IAS charcoals have promising properties based on these analyses. The MYs were 21.77%, 27.18%, and 26.65% for CM, MP, and IC, respectively. Furthermore, the HHV values were 27.16 MJ/kg, 26.65 MJ/kg, and 26.70 MJ/kg, whereas the EY values were 5.91%, 7.24%, and 7.12% for CM, MP, and IC, respectively. The HHV indicates that the charcoals synthesised from the IAS are promising alternatives to traditional tree-type sources, presenting solutions to the challenges posed by felling trees, deforestation, and biodiversity linked to charcoal production. Additionally, the results underscore the twin merits of utilising these abundant and underutilised IAS, which would contribute to weed control, environmental management, and renewable/sustainable energy generation. Future research will concentrate on the optimisation of the carbonisation parameters and product charcoals and explore specialised applications.

2.21. Carbonisation and Characterization of Senna obtusifolia, Flueggea virosa, and Ficus aurea for Sustainable Production of Charcoals

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Invasive plant species (IPS) like Senna obtusifolia (SO), Flueggea virosa (FV), and Ficus aurea (FA) pose environmental and economic problems in Nigeria. Notably, IPS have adverse impacts on native flora, biodiversity, and ecosystems, whilst weakening agricultural productivity and land use effectiveness. However, such plants are characterised by high lignocellulosic content, woody stems, and rapid growth rates, which make them abundant, accessible feedstock candidates for bioenergy recovery and utilisation. Therefore, this study explores the charcoal production potential of SO, FV, and FA through carbonisation. The process was accomplished by heating the samples at a temperature of 600 °C and 30 min residence time, followed by cooling and characterisation of the charcoal mass yield (MY), mass loss (ML), higher heating value (HHV), and energy yield (EY). The results showed that the MY and ML ranged from 21.55% to 29.81%, and 70.19% to 78.45%, respectively, whereas the HHV and EY ranged from 26.41 MJ/kg to 27.18 MJ/kg, and 5.86 MJ to 7.87 MJ, respectively, which indicate adequate results for the sustainable production of charcoals from SO, FV, and FA. The highest HHV and ML were observed in FA, whereas the highest ML and EY were observed in FV. The SO sample revealed intermediate values for most parameters examined in the study. The results demonstrated that carbonisation of such plentiful, yet underutilised plant species is a practical management approach and route for sustainable solid fuels production. Lastly, this strategy helps to ensure environmentally sustainable ecosystem protection and promotes the sustainable livelihoods of locals who can tap into such initiatives.

2.22. Characterization and Preliminary Evaluation of CuO, FeS_2, and Zeolite Y for Tetracycline Adsorption from Simulated Hospital Wastewater

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Tetracycline (TC), a widely used antibiotic, is frequently detected in wastewater effluents, raising concerns about environmental persistence and antibiotic resistance. In this study, the adsorption potential of copper oxide (CuO), iron disulfide (FeS_2), and zeolite Y (HY) was preliminarily assessed for TC removal from aqueous media. CuO and FeS_2 were synthesized via precipitation and hydrothermal routes, respectively, while ammonium zeolite Y was calcined at 550 °C for 3 h to obtain Zeolite HY. The three adsorbents were characterized using FTIR, XRD and SEM-EDX techniques. The FTIR result showed the functional groups at the fingerprint wavebands; Cu-O stretching vibration was seen at 500–600 cm^{-1}, Fe-S vibrational mode was observed at 430–470 cm^{-1} and the Si-O-Si/Al-O-Al asymmetric stretching of the framework of Zeolite HY was seen at 1000–1100 cm^{-1}. The XRD method displayed the characteristic peaks of the individual components while the SEM images of CuO and FeS_2 showed aggregated irregular-shaped particles and flat sedimented particles, respectively. Elemental compositions were illustrated from SEM-EDX, showing the presence and composition of individual element of CuO and FeS_2. All three adsorbents were tested for adsorption in the dark under varying conditions: adsorbent dosage (0.2–1.2 g/20 mL), pH (3–13), contact time (30–150 min), and initial TC concentrations (20–140 mg/L). CuO achieved a maximum TC removal efficiency of 91.4% at pH 9 with 0.6 g/20 mL dosage after 120 min, following pseudo-second-order kinetics. For FeS_2, dosage variation showed an increasing trend in removal, peaking at 81.2% with

1.2 g/20 mL, but performance declined sharply under acidic and basic conditions, likely due to pH-induced surface instability. The HY zeolite also exhibited high adsorption (89.4% at 0.6 g/20 mL). These results suggest all as promising adsorbents for TC, with FeS_2 and HY showing potential for integration into composite materials.

2.23. Chiral-Modified Co-MOF as an Efficient Electrocatalyst for OER

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The purpose of this research is to enhance the overall efficiency of hydrogen production by optimizing the OER via the chiral modification of a catalyst. Hydrogen production through electrochemical water splitting is a promising solution to the energy crisis and may help control harmful emissions from the burning of hydrocarbon-based fuels. The oxygen evolution reaction is a slow and energy-consuming step. The Chiral-Induced Spin Selectivity (CISS) effect can be used to improve the efficiency of the OER by spin-filtering the anodic current. CoBTC MOFs modified with L-glutamine and DL-glutamine (CoBTC-G and CoBTC-DL) were characterized by XRD, Raman, FTIR, elemental analysis, SEM, and TEM and it was confirmed that the MOFs were successfully modified with an amino acid. Pristine and modified MOFs were used as a catalyst to modify the electrode for the OER. The overall performance of the chiral-modified MOF was excellent compared to the racemic mixture, as confirmed by LSV, CVs and chronoamperometry tests. The maximum current density achieved by CoBTC-G is 74.17 mA cm^{-2} at 1.99 (V vs. RHE), while 69.34 mA cm^{-2} and 50.05 mA cm^{-2} were achieved by pristine CoBTC and CoBTC-D (modified with DL-glutamine), respectively. CoBTC, CoBTC-G and CoBTC-DL achieved a current density of 10 mA cm^{-2} at over potential of 384 mV, 392 mV and 424 mV, respectively. The tafel slope values calculated for CoBTC, CoBTC-G and CoBTC-DL are 189, 170 and 234 mV/s, respectively, which shows that the reaction rate of CoBTC-G is faster than that of the other two materials. Electrochemical impedance spectroscopy was performed and the results presented in Nyquist plots show a smaller semicircle at higher frequencies (indicating lower Rct) for CoBTC-G, suggesting better conductivity and faster electron transfer. The purpose of this research is to enhance the overall efficiency of hydrogen production by optimizing the OER via the chiral modification of a catalyst.

2.24. Decision-Making for Water Sustainability: Evaluating Treatment Technologies Through Multi-Criteria Approaches

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Access to clean and reliable water sources is becoming increasingly difficult in many parts of the world. Industrial activity, growing populations, and climate-related disruptions are putting significant stress on available water supplies. These pressures have encouraged the development and use of more advanced technologies for treating both drinking water and wastewater. In recent years, a number of promising solutions have gained attention, including technologies such as membrane bioreactors, reverse osmosis systems, advanced oxidation methods, electrocoagulation setups, granular activated carbon filters, zero liquid discharge approaches, and bioelectrochemical treatments. While each of these technologies has demonstrated success in specific applications, they differ considerably in terms of operating conditions, efficiency, and resource demands. Because of the variety and complexity involved, identifying the most appropriate method for a specific application presents a

substantial challenge. Decision makers often have to balance technical performance with environmental impact, cost, and other practical concerns. In light of this, methods that allow for the structured comparison of multiple alternatives—particularly multi-criteria decision-making (MCDM) approaches—can offer valuable guidance. This study proposes to examine and compare several of the most recognized sustainable water treatment technologies using a decision-making framework. Rather than relying on just one metric, the evaluation will consider a range of factors that are relevant in real-world settings, including both qualitative and quantitative elements. The outcomes of this analysis are intended to support more informed and context-sensitive decisions in water treatment planning, especially in environments where sustainability is an increasingly critical concern.

2.25. Degradation of Fast Green FCF Dye Through Ecologically Sustainable ZnO NPs

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Introduction: Synthetic dyes are widely utilized across numerous industries, but their durability, harmful effects, and resistance to natural degradation processes make them major pollutants, especially in industrial wastewater. Conventional treatment techniques often fail to fully eliminate these substances. Photocatalysis involving semiconductor materials has shown promise as an effective method for degrading the dye under relatively mild conditions. Among the different metal oxide photocatalysts, zinc oxide (ZnO) has attracted considerable interest due to its small band gap, strong stability, affordability, and ability to be activated by visible light.

Methodology: In this study, ZnO nanoparticles (NPs) were synthesised through a green synthesis method using *Livistona chinensis leaf* extract and utilized for photocatalytic degradation of synthetic dyes under visible light. The NPs were characterized by FT-IR, XRD, UV-vis and FESEM techniques. The band gap was also calculated. The photocatalytic activity was tested against Fast Green FCF azo dye.

Results: The produced NPs showed significant photocatalytic efficacy. The photocatalytic potential of the ZnO NPs against Fast green FCF showed 76% photodegradation after 90 min when exposed to visible light.

Conclusion: The study highlights the advantages of utilizing ZnO NPs as a visible-light-activated, cost-effective, and environmentally friendly photocatalyst. These findings suggest that the NPs could be used as a sustainable wastewater treatment.

2.26. Design and Development of a Low-Cost and Compact Real-Time Monitoring Tool for Battery Life Calculation

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Reducing residential energy consumption is critical for achieving global sustainability targets, with windows representing a significant source of solar heat gain and thermal loss. However, their expansive surface area also presents a valuable opportunity for decentralized energy generation. This study presents the design and implementation of a prototype dual-function photovoltaic window system that integrates flexible solar panels for dynamic shading and a compact lithium battery for local energy storage. The methodology

involves developing an experimental setup where translucent, flexible photovoltaic panels are retrofitted onto a standard residential window. The system is connected to a charge controller and a small-capacity lithium-ion battery pack. Key performance metrics, including solar irradiance, power generation efficiency, reduction in thermal transmittance, and battery state of charge, are continuously monitored under varying real-world environmental conditions. The integrated panels can significantly reduce solar heat gain, thereby lowering indoor ambient temperature and reducing the building's cooling load. Simultaneously, the system will generate sufficient electricity to be stored in the lithium battery, providing a self-contained power source for low-draw applications such as lighting or charging personal devices. This research highlights the viability of developing cost-effective, multifunctional building components that transform passive architectural elements into active energy-saving and power-generating systems in terms of green environment goals.

2.27. Development of a Low-Cost Electroporator Using Recycled Electronic Components for Educational and Research Applications

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Electroporators are widely used devices for educational and research purposes, particularly in molecular biology and genetic engineering, where they enable the introduction of foreign DNA into cells through the application of high-voltage electric pulses. Despite their utility, their high cost limits accessibility in educational and research institutions in developing countries, restricting hands-on training and the development of local biotechnological capacities. At the same time, the global increase in electronic waste has reached alarming levels, raising environmental and economic concerns. In this context, the aim of this study was to develop a functional electroporator prototype using components recovered from discarded electronic devices. The device was built using a flyback-based circuit that generated logarithmic decay pulses with a duration of 5.00 ± 0.25 ms. Pulse control was achieved through a simple resistor–capacitor (RC) circuit connected to the gate of a MOSFET, powered with 200 V at the input, and subsequently stepped up by a transformer. Stainless steel needle electrodes were used, with a separation of 1.00 ± 0.05 mm. Performance was evaluated following the protocol described by Sambrook et al. (2001), using Escherichia coli DH5α strains. Transformed cells were cultured in Luria–Bertani (LB) medium supplemented with ampicillin, yielding an average of one colony per 200 μL of culture. The results support the feasibility of building low-cost electroporators from recycled components, contributing to sustainable technology development.

2.28. Diagnosis of the Solid Biofuel Process from Agave Bagasse Through Arena Simulation

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In Mexico, the mezcal industry consumes significant volumes of biomass as thermal energy and generates large amounts of organic waste. In each artisanal production batch, up to 246 m^3 of firewood is burned, resulting in considerable CO_2 emissions and deforestation pressure. Simultaneously, approximately 2.4 tons of lignocellulosic bagasse are produced per 6 tons of fermented agave. This byproduct offers a calorific value (≈16.4 MJ/kg), mak-

ing it a viable alternative as a solid biofuel. This study presents a discrete-event simulation model in Arena™, applied to an artisanal mezcal distillery in Tecamachalco, Mexico, to evaluate the technical feasibility of replacing part of the firewood with processed agave bagasse. The modeled process includes bagasse conditioning, indirect solar drying, grinding, briquetting, final drying, and combustion during distillation. The model incorporates cycle times, machine capacities, human resource availability, and process variability. Key performance indicators such as briquette yield, resource utilization and bottlenecks were analyzed. Sensitivity analysis under varying drying capacities, labor shifts, and demand scenarios identified solar drying as the critical constraint. Improvement strategies such as expanding dryer capacity and adopting hybrid systems were proposed to enhance throughput and energy substitution. The simulation demonstrates the potential to reduce firewood use by up to 30%, lowering environmental impact while valorizing agro-industrial residues. This approach contributes to more sustainable mezcal production, aligned with the principles of circular bioeconomy and rural energy transition.

2.29. Dye Sorption by Biosorbents and Biochars from Olive Pomance

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The escalating presence of dye pollutants in industrial effluents has rendered the pursuit of environmentally benign and economically sustainable remediation strategies increasingly imperative. Among emerging solutions, the application of biosorbents derived from agro-industrial residues, such as olive pomace, has garnered significant interest due to the low cost and promising efficiency of these residues. This study explores the sorption capabilities of biosorbents and biochars synthesized from olive pomane via water-activation and pyrolysis, respectively, for the removal of dye compounds from aqueous solutions. The materials underwent comprehensive characterization through BET surface area analysis, Raman Spectroscopy, Fourier transform infrared spectroscopy (FTIR), elemental analysis and scanning electron microscopy (SEM). Sorption performance was assessed using two representative dyes—Safranin and Methylene blue—while the kinetics, isotherms and pH influence on the sorption process were thoroughly investigated. Both dyes exhibited satisfactory removal rates, with no significant discrepancies observed in the sorption efficiency between the two, indicating the versatility of the material across different dye classes. The results revealed a markedly improved sorption capacity for the pyrolyzed material relative to its water-activated counterpart, a performance attributed to its enhanced porosity and surface area. These findings underscore the potential use of biochar derived from olive pomace as an efficient, low-cost sorbent for dye-laden wastewater. Ultimately, this study highlights the valorization of agri-food by-products as viable tools for wastewater treatment, aligning with broader goals of circular economy advancement and sustainable waste management.

2.30. Dynamic Modelling of a Metal Hydride Reactor During Discharge Through Artificial Neural Network Regression

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In the form of a metal hydride has come forth as a safe and low-pressure storage solution with competitive volumetric energy density. In this technology, hydrogen is stored in a hydride-forming metal, in this study specifically AB5-type metal hydride, through exothermic absorption, which can then be discharged through endothermic desorption. This results in a complex batch system where hydrogen discharge is caused by high-temperature fluid heating the reactor and by extension the metal hydride bed. This in turn increases the hydrogen pressure of the gas surrounding the metal hydride bed which then is released through a regulator to achieve the desired pressure of the discharge hydrogen. This discharge dynamic system as a result is notoriously hard to model and predict. This paper reports the modelling of a metal hydride reactor during its discharge state using neural network regression. This was done by generating a validated finite element model of the reactor which was then used to generate dynamic operational data based on the desired pressure outlet and heating fluid temperature as independent variables. This data was then used to train an artificial neural network using the desired gas pressure, heating fluid temperature, and time as inputs and concentration as the variables the neural network would predict. Regarding model performance, the best-performing artificial neural network model achieved a regression coefficient of 0.9999 and a mean squared error of less than 10^{-5} during training. Likewise, the best-performing neural network model validation using the experimentally observed data achieved a regression coefficient of 0.99 and a mean squared error of less than 10^{-4}. This proves that neural networks can model the complexity of metal hydride reactors during discharge, specifically the HySA-systems Metal Hydride reactor prototype.

2.31. Effect of Pyrolytic Temperature on Biochar's Physicochemical Properties Under Sodium Carbonate Catalyst Impregnation from Green Pea Peels

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Exploiting the circular economy has been a vital resource utilization and energy recovery strategy. This study examined the influence of pyrolytic temperature on the chemical, physical and morphological properties of biochar derived from waste biomass and recommended its suitability for environmental application and energy production. The biochar synthesis was performed by thermal degradation of green pea pods in the presence of Na_2CO_3 catalyst at temperatures of (300–800 °C in 100 °C intervals). The physicochemical characteristics and morphological structures of the produced char were evaluated, including mineral composition, carbon content, functional groups and morphological structures, using basic characterization techniques. The findings indicated that the biochar's specific surface area increased from 0.6836 m^2/g to a maximum of 683.2 m^2/g, whereas the mean pore diameter decreased from 161.67 nm at 300 °C to 1.4774 nm at 600 °C. And later on, it rose to 2.1778 nm at 800 °C. The increase in pyrolysis temperature demonstrated a positive relationship with the biochar's carbonization degree, aromatization and stability. On the other hand, yield, oxygenated functional groups, nitrogen and oxygen reduced, exhibiting a negative relationship. Moreover, the produced biochar materials had improved higher heating value (HHV) of (16.56–23.6 MJ/kg) in comparison to 15.50 MJ in the feedstock. Thus, biochar from waste peels at various pyrolysis temperatures can be effective in the recovery of energy, decontamination of organic and inorganic pollutants in wastewater and agronomic nourishment.

2.32. Effective Photocatalytic Degradation of Tetracycline Antibiotic Using Novel TiO_2_Slag Nanocomposite: Optimization Using Response Surface Model

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Numerous economically disadvantaged countries face substantial challenges in water purification due to the absence of centralized wastewater treatment systems. Consequently, this study investigates the optimal degradation of the antibiotic contaminant tetracycline from wastewater utilizing a TiO_2–slag nanocomposite synthesized via an ex situ method under simulated solar irradiation. The morphology and crystalline structure of the synthesized hybrid material were characterized through scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray diffraction (XRD). Fourier-transform infrared spectroscopy (FTIR) was employed to analyze the elemental composition and functional groups. To evaluate photocatalytic performance, a Box–Behnken design (BBD), integrated with response surface methodology, was used to determine the influence of three operational variables: pollutant concentration (20–40 ppm), catalyst loading (10–50 mg/L), and pH level (3–11), with a fixed reaction duration of 60 min. The experimental matrix, comprising 17 runs, was designed to capture the interactive effects among these variables on degradation efficiency. A reduced quadratic regression model was established, demonstrating strong predictive capability aligned with empirical results. The coefficient of determination (R^2) values for the analysis of variance (ANOVA) were 0.99 and 0.98, indicating statistical significance ($p < 0.05$) of the proposed model.

Among the tested parameters, catalyst dosage emerged as the most influential factor, exerting a notable effect on the photocatalytic reaction, whereas the synergistic interaction between pollutant concentration and pH showed a positive contribution, culminating in a maximum degradation efficiency of 99.92%. Furthermore, an economic assessment revealed the treatment cost to be $0.9438 per cubic meter, signifying a cost-effective solution. These findings highlight the potential application of TiO_2–slag nanocomposites as an efficient and low-cost material for industrial wastewater remediation, thereby reducing dependence on expensive chemical reagents.

2.33. Energy-Saving Strategies for Enhancing Outdoor and Semi-Outdoor Thermal Comfort in Smart Cities: A Systematic Review

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Thermal comfort in urban environments is increasingly being addressed through smart, energy-efficient strategies, especially as cities adapt to rising temperatures and sustainability mandates. This study presents a systematic review of recent research on energy-saving methods for improving outdoor and semi-outdoor thermal comfort in smart

cities. Articles were sourced from Scopus and Web of Science (2020–2025), and analyzed based on applied methods, effectiveness, and geographic distribution.

The reviewed literature highlights five main categories of strategies: (1) passive interventions (e.g., vegetation, phase change materials, reflective coatings), (2) smart materials (e.g., thermochromic windows and bioinspired textiles), (3) AI-driven HVAC and thermal control systems, (4) sensor-based human-centric feedback loops, and (5) integrated energy management systems (EMS) including residential energy hubs. China and the USA lead in research output, with significant contributions from Spain, India, and the Netherlands.

Reported effectiveness varies by method and context: passive solutions reduced MRT by 2–5 °C and surface temperatures by up to 20 °C; AI-based controls achieved HVAC energy savings of 20–30%; and thermochromic coatings lowered cooling demands by 10–25%. Despite technological advances, relatively few studies incorporate human thermal perception data or prioritize equity in thermal comfort distribution.

This review identifies key innovation trends and proposes a classification framework for energy-efficient thermal strategies in smart urban contexts. Future research should emphasize user-centered metrics, interdisciplinary integration, and implementation across varying climate zones, especially in vulnerable regions.

2.34. Enhancing Biogas Production Using Organic Waste as Clean Energy for Sustainable Development

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This study investigates the potential of kitchen waste sourced from five restaurants and traditional halls within Kwame Nkrumah University of Science and Technology (KNUST) for biogas production via anaerobic digestion for the first time. A total of 6868 kg of waste, including cassava peels (39.7%), plantain peels (36.1%), and yam peels (24.2%), were collected over three weeks. Laboratory analysis assessed total solids (TSs), volatile solids (VSs), and ash content of representative waste samples. The TS values ranged from 14.82% to 35.26%, while VS values, indicative of biodegradable potential, spanned 53.3% to 83.7%, confirming high methane yield potential. Ash content remained below 10%, reinforcing the organic-rich composition.

Biogas yield was measured per kilogram of feedstock, with cassava and plantain peels yielding an average of 0.45–0.52 m^3 CH_4/kg, outperforming yields reported in similar Ghanaian municipal waste studies by over 20%. Compared to traditional reliance on livestock manure with typical methane yields of 0.20–0.30 m^3 CH_4/kg, the kitchen waste feedstock demonstrated superior energy conversion efficiency.

This research concludes that kitchen waste in high-density institutional environments provides a sustainable and efficient substrate for decentralized biogas generation, aligning with circular economy models. By diverting organic waste from landfills and reducing methane emissions, this method offers an affordable and environmentally sound solution to campus energy and sanitation challenges. The findings support broader integration of kitchen-waste-based digesters in urban institutions, with potential replication across West Africa to improve waste valorization and reduce reliance on fossil fuels.

2.35. Enzyme-Assisted Extraction of Bioactive Compounds from Origanum dictamnus L.

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Origanum dictamnus L. is a medicinal plant known for its rich content in bioactive compounds. The plant cell wall consists of various structural polysaccharides such as cellulose, hemicellulose, and pectin, along with lignin, proteins, and bioactive compounds. These compounds are either trapped within the plant cell wall or free in the cytocol of the plant cell. Enzyme-assisted extraction (EAE) is a green technology that relies on the enzymes ability to selectively degrade the plant cell wall, thereby facilitating the release of bioactive compounds.

In the present study, EAE was applied to extract bioactive compounds from the leaves of *Origanum dictamnus* L. using the commercial enzyme preparation Cellic® CTec3 HS (Novozymes) and was compared to conventional extraction with ethanol–water mixtures of various concentrations. A Taguchi experimental design was applied to determine the optimal EAE conditions. The variables were enzyme loading (50, 100, and 200 U/mg), solid-to-liquid ratio (1, 4, and 7% w/v), and extraction time (1, 3, and 6 h). The responses were total phenolic content (TPC) and total flavonoid content (TFC). Conventional extraction was performed using ethanol–water mixtures of 0–100% v/v. TPC was determined using the Folin–Ciocalteu method and TFC with the aluminum chloride method. EAE achieved the highest TPC yield of 164.8 $\pm$ 5.2 mg GAE/g DW, at 1% w/v, 100 U/mg, and 6 h. The maximum TFC yield reached 92.5 $\pm$ 5.7 mg CAE/g DW with 7% w/v, 100 U/mg, and 1 h. In comparison, conventional extraction with 40% ethanol (v/v) gave the maximum TPC of 133.2 $\pm$ 0.5 mg GAE/g DW and TFC of 67.9 $\pm$ 0.9 mg CAE/g DW. These results support the potential of EAE as an efficient and sustainable method for the extraction of bioactive compounds from *Origanum Dictamnus* L.

2.36. Evaluating the Extraction Efficiency of Choline Chloride–Malic Acid DES Against Conventional Solvents for Quercetin and Caffeic Acid: A Green Approach

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Quercetin and caffeic acid are bioactive phytochemicals with significant pharmaceutical value due to their antioxidant, anti-inflammatory, and therapeutic properties. The growing demand for efficient and environmentally friendly extraction methods has spurred interest in green solvents such as deep eutectic solvents (DESs). In this study, a choline chloride–malic acid (ChCl–MA) DES was evaluated as a sustainable alternative to conventional solvents like ethanol for extracting quercetin and caffeic acid. Density Functional Theory (DFT) calculations were used to examine the molecular interactions and extraction potential of ChCl–MA compared to ethanol. All computations were performed using the wB97X-D functional, which accounts for dispersion interactions, with initial geometries optimized at the PM3 level. A dual basis set (6-31G(d)/3-21G*) was applied in the vacuum (gas phase) to ensure reliable results. The ChCl–MA DES was found to be thermodynamically stable and chemically more reactive than ethanol, as indicated by its lower HOMO–LUMO energy gap. It also exhibited stronger binding interactions with the target compounds: -1.63 eV for quercetin and -0.35 eV for caffeic acid, compared to ethanol's -0.30 eV and -0.33 eV, respectively. These findings suggest that ChCl–MA may offer enhanced extraction potential relative to ethanol. However, it is important to note that these conclusions are based on vacuum (gas-phase) DFT simulations, which do not fully account for solvent-phase dynamics (solvation effect) or entropy effects. Therefore, while the results

offer valuable theoretical insight into solvent–solute interactions, further experimental and solution-phase computational studies are necessary to validate the practical efficiency of ChCl–MA in real extraction scenarios.

2.37. Experimental Design for Hydrogen Production from Sodium Borohydride Reaction on UiO-66 and ZIF-67 Catalysts

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Experimental design is utilized to detect the effect of parameters on the process of hydrogen production. Thanks to experimental design methods, time and money consumption can be decreased. In addition to that, decreasing hazardous solvent and chemical consumption is crucial to the green chemistry approach. Regarding the synthesis of MOFs, solvents like methanol and expensive chemicals like imidazole salt are needed. In addition to that, after MOF synthesis, there are many more steps, like collecting crystals and drying them. Analysis of covariance (ANCOVA) is one of the experimental design tools. ANCOVA is formed from the fusion of two statistical methods, which are analysis of variance (ANOVA) and regression analysis. For this analysis, it is necessary to select one independent variable as a factor. At this time, other independent variables are called covariates. ANCOVA can be applied in various fields like medicine, agriculture, biology, and engineering. For the reaction producing H_2 from $NaBH_4$ hydrolysis, the researchers used response surface methodology (RSM) and ANOVA. To the best of the authors' knowledge, there is scarce research about the optimization of H_2 production from the NaBH4 hydrolysis reaction with ANCOVA. This study aimed to determine the effect of several parameters (catalyst amount, time, reactant amount) on hydrogen yield from $NaBH_4$ hydrolysis on several MOFs used in the literature.

2.38. Experimental and In Silico Studies to Evaluate the Corrosion Inhibition Potential of Prawn Shell-Derived Chitosan on Mild Steel in Saline Solution: Effect of Temperature and Concentration

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Chitosan as a natural polymer has gained considerable attention in recent years due to its organic nature and unique chemical properties. In this study, chitosan extracted from prawn shells was studied as a green corrosion inhibitor in saline solution (3.5% NaCl) under different temperature conditions, 298 K, 303 K and 308 K, and different saline solution concentration ranges of pH 6.5, 7.5, and 8.5. The prepared chitosan was characterized by Fourier Transform Infrared Spectroscopy (FTIR) and X-ray diffraction (XRD). Electrochemical studies (potentiodynamic polarization) were performed to study the corrosion rate (CR) and the inhibition efficiency (%IE). The metal surface was studied using Scanning Electron Microscopy (SEM) and X-ray Fluorescence (XRF) in order to determine the adsorption capacity of the inhibitor and confirm that a protective barrier was formed that protected the mild steel from rapid corrosion. Quantum simulations were carried out through density functional theory (DFT) using the Gaussian 09 program. Molecular dynamics was performed in Material studio software (2020) using the Forcite module and

applying the COMPASS forcefield simulation, to study the interaction of the inhibitor with the metal surface at different temperatures, and therefore calculate the interaction energy. The study shows that an increase in temperature tends to speed up the corrosion rate, and an increase in the inhibitor amount shows a decline in the overall corrosion rate.

2.39. Exploring the Efficacy of Pd-Au-Decorated ZnO Nanoparticles Obtained Through Green Synthesis as a Sustainable Approach for Water Treatment

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Addressing water contamination with hazardous pollutants, particularly nitrites with strong carcinogenic potential, is an essential priority in environmental remediation efforts. This research explored the photoreduction of nitrate in drinking water, comparing plain ZnO nanoparticles (ZnO NPs) with Pd-Au-decorated ZnO NPs. In the first step, ZnO NPs were synthesized using a simple and environmentally friendly precipitation method using black tea solid waste extract. In the second step, bimetallic nanoparticles were obtained using a green chemistry method from Au and Pd precursors (at a 1:1 molar ratio) in a tannic acid solution. The Pd-Au/ZnO photocatalytic material was obtained by dispersing bimetallic nanoparticles, previously dissolved through sonication in deionized water, onto ZnO. Both the ZnO and Pd-Au/ZnO NPs were characterized in terms of their structural crystallinity and morphology using XRD, SEM-EDX, and TEM. The photocatalytic efficiency of the synthesized ZnO and Pd-Au/ZnO NPs was evaluated according to their ability to degrade nitrates from water, in the absence and presence of formic acid as a reducing agent and/or a hole scavenger, under UV irradiation with a 125 W Hg lamp. Compared to the ZnO NPs, the catalysts loaded with bimetallic Pd-Au nanoparticles demonstrated excellent N_2 selectivity in the photocatalytic reduction of nitrate in the presence of formic acid. The maximum photocatalytic activity and N_2 selectivity were achieved using the Pd–Au/ZnO NPs, with a total metal loading of 1 wt%. A possible photocatalytic mechanism was proposed. Upon UV irradiation, zinc oxide (ZnO) generates electrons that are transferred to the bimetallic nanoparticles. Subsequently, protons (H+) adsorbed onto the surface of the metal particles facilitate the reduction of nitrate ions (NO_3^-). These materials are expected to exhibit a high photocatalytic performance by enhancing the rate of photoexcited electron capture and reducing recombination effects, thanks to the electron storage capacity of the palladium–gold (Pd-Au) nanoparticles.

2.40. Fabrication of Gadolinium-Doped Nickel Ferrite–Nylon 11 Composite via Hydrothermal Route for Electromagnetic Shielding Application

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Ferrite–polymer composites, which merge the magnetic properties of ferrites with the flexibility of polymers, present a remarkable combination of strength and versatility, unlocking opportunities for innovative applications. In this study, $NiGd_{0.1}Fe_{1.9}O_4$ spinel ferrite nanoparticles were synthesized by adopting a hydrothermal method. Synthesized nanoparticles were then incorporated into a nylon 11 matrix to form a $NiGd_{0.1}Fe_{1.9}O_4$/Nylon composite using the tape casting method. The addition of spinel ferrite nanofillers enabled precise tuning of the electromagnetic shielding properties of the composites. Transmission electron microscopy (TEM) shows the polyhedral crystal structure of the synthesized nanoparticles with an average particle size of 20 nm. BET analysis shows mesoporous nanoparticles with a specific surface area of 40.701 m^2/g. X-ray diffraction (XRD) with Rietveld refinement confirmed the formation of single crystal phases, which corresponds

to the *Fd3m* space group with a lattice constant of 8.3614 Å. The FTIR spectrum with an absorption band of around 400–600 cm^{-1} revealed the vibration of positive ions at tetrahedral and octahedral sites, characteristic of spinel ferrite formation. Field emission scanning electron microscopy (FE-SEM), coupled with energy-dispersive X-ray spectroscopy (EDS), provided insights into the morphology, stoichiometric and uniform distribution of ferrites within the polymer matrix. FTIR of the composite revealed the formation of the metastable ferroelectric phase of nylon 11. Finally, magnetic and dielectric properties of the composite were evaluated across varying ferrite concentrations.

2.41. Facile Wet-Chemical Synthesis of Graphene Oxide/Hydroxyapatite Composite for Potent, Accelerated, and Synergistic Sonophotocatalytic Degradation of Diclofenac Under Light and Ultrasound Irradiation

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The widespread disposal of pharmaceutical wastes, particularly diclofenac (DCF), poses a significant threat to aquatic ecosystems. The current degradation methods, including biological treatments and standalone advanced oxidation processes, often prove insufficient, leaving residual DCF concentrations. This study proposes a novel solution using a rapidly synthesized graphene oxide/hydroxyapatite (GO/HAp) nanocomposite via wet-chemical precipitation to enhance DCF degradation through synergistic sonophotocatalysis. The synthesized nanocomposite's structure was confirmed using FTIR, XRD, and SEM analyses, revealing the successful formation of a hexagonal HAp phase on GO sheets. Optimization of the sonophotocatalytic parameters revealed that pH and loading significantly influenced degradation, while time had a less pronounced effect. The optimal conditions (a pH pf 4, 45 mg GO/HAp, 30 min) achieved a remarkable 93.86% DCF degradation, significantly outperforming standalone photocatalysis (72.76%) and sonolysis (63.76%). This enhanced performance is attributed to the synergistic effect of sonophotocatalysis, which increases the active surface area and radical generation, coupled with the high surface area and adsorption capacity of the GO/HAp nanocomposite. This research demonstrates that rapid wet-chemical synthesis of the GO/HAp nanocomposite, coupled with an optimized sonophotocatalytic process, offers a potent, accelerated, and efficient method for degrading DCF, paving the way for improved pharmaceutical wastewater treatment. Ultimately, this research provides a foundation for developing effective water treatment solutions to combat pharmaceutical contaminants.

2.42. Forecasting Gold–Cyanide Removal onto Polycarbonate Using Automated Machine Learning (AutoML) with Feature Engineering Techniques

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The intricate interaction between essential process parameters and their impact on gold–cyanide leaching recovery presents an environmental challenge for mining companies. Although polycarbonate materials demonstrate potential as adsorbents for gold-cyanide extraction, improving the adsorption process demands robust predictive models capable of accommodating variability among various operational parameters. This work proposed the development of a machine learning model that forecasts gold–cyanide leaching removal uti-

lizing the architecture of Automated Machine Learning (AutoML) and feature engineering approaches in MATLAB. The experimental feed data comprised flow rate (900–1000 m^3/h), pH (10–11), and polycarbonate concentration (7–10 g/L) as the independent variables mapped against cyanide concentration (200–300 ppm) and gold concentration (0.5–2 ppm) as the dependent variables. The dimensionality reduction technique enabled the elimination of redundant input characteristics that exert negligible influence on gold cyanide leaching removal during the preprocessing phase. Evaluation of the regression model, following training and hyperparameter optimization, identified the decision tree (DT) as the most effective model, achieving a coefficient of determination (R^2) of 0.998, a mean squared error (MSE) of 0.025, and a root mean square error (RMSE) of 0.1581. Feature selection employing the F-test identified pH as the predominant variable during model training. The proposed prediction model offers a deployable system designed to optimize mining operations and save operational expenses. This also underlines the reliability and rapid implementation of AutoML in these domains.

2.43. Groundwater Quality Physico-Chemical Analysis for Sustainable Water Management

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Groundwater plays a crucial role in regions like southern Uzbekistan, where surface water is limited. This study investigates the physico-chemical properties of groundwater in the Koson district (Kashkadarya region) to assess its suitability for drinking and sustainable use. Four samples (S1–S4) collected from different depths (100–1650 m) were analyzed for pH, electrical conductivity (EC), total alkalinity, total hardness (TH), calcium hardness (CaH), magnesium hardness (MgH), and total dissolved solids (TDS). Ionometric and elemental analyses were also conducted using standard methods, including ICP-MS. While all samples had a pH within WHO-recommended limits (6.5–8.5), EC, TDS, and hardness values exceeded permissible levels in most cases. Sample S2 recorded the highest EC (6295 μS/cm) and TDS (7600 mg/L), indicating excessive salinity. Total hardness in some samples reached up to 930 mg/L, suggesting unsuitable conditions for direct consumption. Elemental analysis revealed relatively high sodium, calcium, and magnesium levels, though within safe limits. Ionometric data indicated possible contamination from agricultural and anthropogenic sources, including elevated nitrate (NO_3^-) and ammonium (NH_4^+) levels. The findings suggest that while groundwater can be a critical water source, proper treatment is required before use. Regular monitoring and management are essential to prevent health risks and ensure long-term water sustainability in the region.

2.44. Green Solvent Strategies for BTX Remediation: From Pollution to Prevention in Industrial Wastewater

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Aromatic hydrocarbons such as benzene, toluene, and xylene (BTX) are persistent pollutants in refinery wastewater and are known for their high toxicity, carcinogenicity, and adverse effects on human health and aquatic ecosystems. Prolonged exposure to BTX, even at low concentrations, has been linked to respiratory disorders, neurological impairment, and increased cancer risk, especially in communities located near petroleum refining facilities. This study investigates the application of a deep eutectic solvent (DES), a class of green solvents composed of hydrogen bond donors and acceptors, for the efficient extraction of BTX from refinery waste. Unlike conventional organic solvents, DESs are biodegradable, non-volatile, and tunable, making them safer for both the environment and human health. Using a TBAB–decanoic acid-based DES system, various compositions were synthesized, and only the one that remained stable was evaluated for BTX extraction efficiency through liquid–liquid extraction experiments. Key performance indicators included solvent mass fraction, stirring speed, time and temperature, and the reusability of the DES systems. Results revealed that DES exhibited high affinity for BTX compounds, with extraction efficiencies exceeding 80% for benzene and toluene under optimized conditions. The findings demonstrate the potential of DES not only as effective extractants but also as health-conscious alternatives in industrial wastewater treatment. This work highlights the relevance of green chemistry innovations in mitigating environmental and public health risks, aligning with global efforts toward cleaner water and safer communities.

2.45. Green Synthesis of Iron Oxide Nanoparticles Using Moringa Oleifera Leaf Extract for the Adsorptive Removal of Arsenic from Groundwater in Southern Punjab, Pakistan

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Arsenic contamination in groundwater poses a significant threat to public health and agricultural sustainability in Southern Punjab, Pakistan, where naturally occurring arsenic exceeds WHO safety limits. Traditional remediation techniques are often costly, energy-intensive, and environmentally unfriendly. Iron oxide nanoparticles (Fe_2O_3 NPs) have demonstrated significant potential for adsorbing heavy metals, particularly arsenic, from water and soil. The green synthesis approach using plant extracts minimizes chemical toxicity and enhances environmental compatibility. This study aimed to synthesize iron oxide nanoparticles using *Moringa oleifera* leaf extract, removing arsenic (As^{3+}/As^{5+}) from arsenic-affected regions in Southern Punjab. Iron oxide nanoparticles were synthesized via aqueous extraction of *Moringa oleifera* leaves, acting as a reducing and stabilizing agent. The nanoparticles were characterized using UV–Vis spectroscopy, FTIR, XRD, and SEM. Batch adsorption experiments were conducted under varying pH, contact time, and nanoparticle dosages. Groundwater samples were analyzed using atomic absorption spectroscopy. The green-synthesized Fe_2O_3 NPs exhibited spherical morphology with an average size of 20–40 nm. The maximum arsenic removal efficiency (92.6%) was observed at pH 6.5 within 60 min. The nanoparticles retained over 85% efficiency after three reuse cycles, indicating good stability and reusability. The study demonstrates that *Moringa oleifera*-mediated iron oxide nanoparticles provide an eco-friendly, cost-effective, and efficient solution for arsenic remediation in groundwater.

2.46. High-Performance Nanosized Co/rGO Composite as an Efficient Oxygen Electrode Material

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In the last few decades, investigations of low-cost, stable, highly active, and fast-synthesizing electrocatalysts for the oxygen evolution and reduction reaction (OER and ORR) have been the main focus of electrochemical examinations. These two reactions are key half-reactions in rechargeable metal–air batteries (MABs) and unitized regenerative fuel cells (URFCs), which are considered eco-friendly and promising energy storage technologies. URFCs can function in two modes: in electrolysis mode, water is split into hydrogen and oxygen via the hydrogen evolution reaction (HER) and OER; in fuel cell mode, hydrogen and oxygen are used to generate electricity and water through the hydrogen oxidation reaction (HOR) and ORR. Similarly, MABs rely on OER and ORR as the primary reactions occurring at the air cathode during charging and discharging cycles. Although noble metal-based catalysts such as iridium or ruthenium oxides (IrO_2/RuO_2) and platinum (Pt) are regarded as standard electrocatalysts for OER and ORR, their use is limited by sluggish kinetics when applied in the opposite reaction—Pt for OER and IrO_2/RuO_2 for ORR.

In this work, Co/rGO was synthesized via chemical synthesis, characterized by scanning electron microscopy, and tested for OER/ORR in alkaline media. The Co/rGO electrodes demonstrated comparable or superior performance to state-of-the-art OER/ORR catalysts, with enhanced stability and cost-effectiveness, highlighting their potential as practical alternatives in metal–air batteries and fuel cells.

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2.47. Hybrid Electric–Pneumatic Propulsion System for Sustainable Urban Transportation: Design and Energy Management Optimization

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Urban transportation necessitates the development of efficient and sustainable propulsion technologies capable of adapting to future infrastructure. This study presents a hybrid electric–pneumatic propulsion system for lightweight urban vehicles that addresses range limitations and environmental concerns through intelligent energy management.

The system utilizes a 10–15 kW brushless DC motor and a 7–10 kWh lithium-ion battery (72 V/96 V) as the primary drive to achieve a range of 50–70 km. The pneumatic subsystem employs an aluminum composite tank (80–120 L) pressurized at 200–300 bar to provide auxiliary power during emergencies (when the battery is below 15%) and when ascending steep inclines (>8%).

A pivotal innovation is the dual-mode energy management system, which dynamically allocates power between the electric and pneumatic subsystems based on the battery's state of charge, air pressure, the vehicle load, and terrain. This configuration facilitates seamless transitions, thereby optimizing the energy distribution and system efficiency.

The vehicle's carbon fiber chassis contributes to its lightweight design, with a weight of less than 500 kg, thereby enhancing its acceleration performance. Preliminary calculations

indicate that the vehicle will demonstrate robust competitiveness, with maximum speeds ranging from 70 to 90 km per hour. An environmental assessment indicates that the vehicle emits no local pollutants and generates 15–20 g CO_2/km well-to-wheel emissions with a coal grid. This results in a reduction of less than 5 g CO_2/km when utilizing renewable energy sources.

In contrast to unsuccessful hybrid air systems (such as the Peugeot Hybrid Air and Tata/MDI AirPod), which demonstrate limited efficiency gains, this approach utilizes pneumatic assistance in a targeted manner, exclusively during periods of high-torque demand. This approach has been demonstrated to achieve energy savings while extending battery life. The system employs existing electric vehicle (EV) charging infrastructure in conjunction with standard air compression facilities, thereby ensuring its feasibility for implementation in urban micro-mobility contexts.

2.48. Integrated DFT Study of CO_2 Capture and Its Utilization in Gingerol Extraction Using Choline Chloride–Lactic Acid Deep Eutectic Solvent

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Carbon dioxide (CO_2) emissions remain a pressing global concern due to their disproportionately large contribution to greenhouse-gas-driven climate change. CO_2 is released through multiple anthropogenic processes, including industrial activity, transportation, and residential energy use. To mitigate its environmental impact, sustainable carbon capture and utilization (CCU) strategies are essential—especially those that can transform captured CO_2 into valuable products. This study aimed to investigate, using Density Functional Theory (DFT), the potential of a choline chloride–lactic acid deep eutectic solvent (ChCl–Lac DES) to serve as a dual-function system for both CO_2 capture and gingerol extraction, contributing to green pharmaceutical applications. All calculations were performed using the wB97X-D functional with PM3-optimized geometries, employing a dual basis set in the gas phase to account for dispersion effects. The DES showed a significantly more negative CO_2 binding energy (-0.86 eV) compared to monoethanolamine (MEA, -0.234 eV), confirming superior CO_2 affinity. Additionally, CO_2 demonstrated moderate binding with 6-gingerol (-0.17 eV), supporting its viability in pharmaceutical extraction. Notably, the DES exhibited an even stronger interaction with 6-gingerol (-1.87 eV), highlighting its potential as a green extraction solvent following CO_2 capture. These findings confirm ChCl–Lac DES as a promising candidate for integrated CCU systems, enabling both carbon mitigation and value-added chemical recovery.

2.49. Interface Engineering in Hybrid Energy Systems: A Case Study of Enhancing the Efficiency of a PEM Fuel Cell with Gas Turbine Integration

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Integrating electrochemical fuel cells and internal combustion units can enhance energy power systems' total efficiency and sustainability. This study presents a promising solution by integrating a Proton Exchange Membrane Fuel Cell (PEMFC) with a mini gas turbine system, forming a hybrid system named the "Oya System." This approach aims to mitigate the efficiency losses of gas turbines during high ambient temperatures.

The hybrid model is designed using Aspen Plus for modeling and the EES simulation program for solving mathematical equations. The primary objective of this research is to enhance the efficiency of gas turbine systems, particularly under elevated ambient temperatures. The results demonstrate a notable increase in efficiency, rising from 37.97% to 43.06% at an ambient temperature of 10 °C (winter) and from 31.98% to 40.33% at an ambient temperature of 40 °C (summer). This improvement, ranging from 5.09% in winter to 8.35% in summer, represents a significant achievement aligned with the goals of the Oya System. Furthermore, integrating PEMFC contributes to environmental sustainability by utilizing hydrogen, a clean energy source, and reducing greenhouse gas emissions. The system also enhances efficiency through waste heat recovery, further optimizing performance and reducing energy losses. This research highlights the critical role of interface engineering in the hybrid system, particularly the interaction between the PEMFC and the gas turbine. Integrating these two systems involves complex interfaces that facilitate the transfer of electrochemistry, energy, and materials, optimizing the overall performance. This aligns with the conference session's focus on green technologies and resource efficiency. The Oya System exemplifies how innovative hybrid systems can enhance performance while promoting environmentally friendly processes.

2.50. Investigation into the Effect of Ultra-Fine Grinding of Low-Grade Cyanide Tailings Pyrite Concentrate for the Recovery of Gold

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This study investigates the influence of particle grind size on metal dissolution, with a specific focus on improving gold recovery from pyrite-bearing low-grade cyanide tailings. Gold often exists as fine inclusions within pyrite, making it complex to recover using conventional methods. To address this challenge, both ultra-finely milled and unmilled pyrite concentrates were experimented in a leaching solution containing 3 kg/ton of sodium cyanide. The leaching process was conducted under controlled conditions, with pH maintained above 9.5 using unslaked lime and atmospheric oxygen present to enhance the reaction environment. A pulp density of 1.45 kg/L was used during the 24-h leaching test. Samples were collected at intervals of 6, 9, 12, and 24 h from a well-agitated leach drum, and the resulting solutions were analyzed to assess gold recovery. The experimental results demonstrated a clear relationship between finer grind size and improved gold dissolution. Notably, reducing the concentrate grind size from 32 µm to 25 µm led to a significant increase in gold extraction efficiency. Furthermore, a comparison between mill feed and mill product revealed a gold recovery increase from 47% to 62%, emphasizing the importance of ultra-fine grinding in unlocking encapsulated gold. This enhanced recovery is attributed to the improved liberation of gold particles, which allows for more effective interaction with the leaching solution. Consequently, these findings confirm that grind size is a key variable influencing the success of leaching processes for pyrite-hosted gold. This study highlights the value of particle size optimization in maximizing recovery from low-grade refractory cyanide tailings.

2.51. Investigation of the Effectiveness of Waste Coffee Grounds in Nickel Removal from Aqueous Solution—A Green Chemistry Perspective

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Nowadays, biomass-based materials are gaining prominence in environmental remediation issues due to their affordability, environmental friendliness, and ease of accessibility. Traditional adsorption is the most widely used strategy for removing textile dyes, heavy metals, and hazardous substances from water. Nickel is one of the most extensively studied metals in catalysis research, particularly in gas- and liquid-phase reactions. In this study, the aim was to remove nickel from an aqueous solution using Turkish coffee grounds. For this reason, adsorption experiments were carried out on coffee grounds, an agricultural waste, at room temperature, with different adsorbent amounts (0.05 and 0.07 g), adsorption times (15–60 min), and adsorbent types calcinated at several temperatures (300–700 °C) with a 0.4 g/L initial Ni(II) solution concentration and a 200 rpm shaking rate in a water bath. After that, based on UV-VIS results, Removal Efficiency (RE, %) and Adsorption Capacity (AC, mg/g) values were calculated. Because the coffee waste released its color to the adsorption media, absorbance values were read for both nickel-included and -excluded solutions. The maximum RE value was obtained as being 98% for 0.07 g of adsorbent that was calcinated at 300 °C after 30 min of adsorption at room temperature. In addition, the maximum AC value was found to be 284 mg/g for 0.05 g of adsorbent that was calcinated at 500 °C after 45 min of adsorption at room temperature. In the literature, maximum adsorption capacity values were in the range of 0.13–60.20 mg/g for several biomass-based adsorbents for Ni (II) removal [1]. So, it was thought that the biomass calcination procedure could be effective for Ni (II) removal from water. It is thought that this study creates an alternative green way to clean wastewater using biomass wastes.

[1] Shroff, K.A.; Vaidya, V.K. (2011). Kinetics and equilibrium studies on biosorption of nickel from aqueous solution by dead fungal biomass of Mucor hiemalis. Chemical Engineering Journal, 171(3), 1234–1245.

2.52. Investigative Analysis of the Key Physical and Chemical Properties of Processed Recovered Carbon Black to Establish a Quality Benchmark and Consistency

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The demand for recovered carbon black (rCB) is growing rapidly; the main reason for this growth is the rising demand for sustainable alternatives to carbon black. This growth aligns with the United Nations' sustainable development goals (SDGs) 9, 11, 12, and 13 because it promotes the recycling of waste tires through pyrolysis into products, hence reducing the reliance on fossil fuels used to make carbon black. It also supports the development of sustainable products, thus reducing emissions and supporting the development of circular economy products. This expansion, however, will incur critical challenges associated with the large production, handling, and transportation requirements.

A new rCB beneficiation plant in South Africa aims to enter into the rCB manufacturing market, but to do this, it needs to not only optimize its process but also the products for ease of handling and transportation. However, the inherent variability and presence of contaminants in and low bulk density of rCB contribute to inconsistent material properties and significant dust generation during handling. Therefore, this new plant aims to standardize its rCB product through the development of proprietary treatment methods and further aims to reduce the dust by densifying the rCB through pelletization.

The objective of this study is to investigate the influence of these treatments and pelletization parameters on rCB quality. Raw and treated rCB samples were collected from the plant, and pellets were produced under varying binder conditions. Analytical

characterization included bulk density measurements, proximate analysis (ash, volatile, and moisture content), ash composition (XRF), laser particle size analysis, and gas adsorption analysis (BET).

These tests aimed to assess how treatment and densification influence surface area, particle distribution, compositional stability, and pellet quality. Preliminary findings show a lower volatile content at a treatment temperature above 250 °C, with an average of 20% volatile matter removal when compared to the raw material.

2.53. Isolation and Purification of Lectin-like Protein from Terminalia Catappa Seeds Using Combination of Chromatographic Techniques

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Lectins are a wide group of proteins found in plants, animals, and marine organisms. These proteins are characterized by their remarkable ability to bind carbohydrates, playing critical roles in various biological processes, such as cell recognition, immune response, and pathogen defense. Plant-derived lectins, in particular, have shown significant medicinal potential, including antifungal, antiviral, and anti-inflammatory properties. However, to fully harness the therapeutic benefits of plant lectins, efficient extraction and purification techniques are essential. *Terminalia catappa*, commonly known as the tropical almond tree, has been used in traditional medicine for various therapeutic purposes, including antimicrobial, anti-inflammatory, antitumor, and antioxidant effects. The seeds of this plant contain bioactive compounds, among which lectins play a crucial role. It has been reported that lectins are glycoproteins exhibiting specificity towards certain carbohydrate moieties. This property is made use of in the purification of lectins and other glycoproteins using the technique of affinity chromatography. Due to the presence of sugar residues, lectins can demonstrate hemagglutination activity. This study aimed to isolate and purify lectin-like proteins from the seeds of the medicinally important *Terminalia catappa* plant. Lectin was isolated using phosphate-buffered saline (PBS) and purified through a series of steps including ammonium sulfate precipitation, dialysis, gel filtration, and affinity chromatography. The saline extract had a protein concentration of 1.5 mg/mL, while after performing gel filtration and affinity chromatography, the concentration was found to be 0.9 mg/mL and 0.7 mg/mL, respectively. A single peak obtained on the affinity column indicated the lectin's homogeneous form with a simultaneous increase in the specific activity of the lectin.

2.54. Microreactors for Drinking Water Treatment: Photocatalytic Removal of Nitrosamines

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Microreactors can serve as advanced treatment units for end-of-pipe solutions in drinking water purification. They provide high surface-area-to-volume ratios and precise control over the reaction conditions, enabling a superior mass and heat transfer performance compared to that of conventional reactors. In the context of advanced oxidation processes, miniaturized flow reactors enhance the degradation efficiency for persistent pollutants by promoting effective mass transport under laminar flow conditions. The reduced diffusion distance between the aqueous phase and the immobilized catalyst layer minimizes mass transfer limitations. This effectively sorts out one of the main challenges associated with heterogeneous photocatalysis. Equally, nitrosamines are hazardous disinfection byproducts formed during water treatment when nitrogenous precursors react with chlorine or chloramine. Particularly, N-nitrosodimethylamine (NDMA) is among the most frequently detected nitrosamines, with a World Health Organization (WHO) guideline value of 100 ng/L in drinking water due to its carcinogenic potential. In this study, the degradation efficiency of a tandem microreactor system was evaluated. The system comprised two continuous-flow microreactors operated in series: the first consisted of a UV-irradiated column packed with TiO_2 immobilized on a biopolymeric matrix, while the second contained an activated carbon-packed bed. An aqueous NDMA solution (1 ppm, pH 3, 20 °C) was introduced under plug-flow conditions, with the temperature and pressure regulated via a Peltier module and a pressure control unit. NDMA degradation was monitored using liquid chromatography–tandem mass spectrometry (LC-MS/MS), revealing a removal efficiency of 87.6%.

2.55. Mathematical Modeling of Sustainable Cu(0)-RDRP: Methyl Methacrylate in Cyrene® at Ambient Temperature

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Precise control over polymer molecular architecture is critical for the development of advanced functional materials with tailored properties. Reversible Deactivation Radical Polymerization (RDRP) techniques enable the synthesis of well-defined polymers under mild and scalable conditions, making them highly suitable for industrial applications. Among these methods, Cu(0)-mediated polymerization stands out for its use of a reusable copper-wire catalyst, low transition-metal concentrations, and ambient temperature operation. These features significantly reduce purification costs, energy consumption, and environmental impact, aligning with the principles of green chemistry.

Notably, the polymerization of methyl methacrylate (MMA) proceeds efficiently in Cyrene®, a bio-based, non-toxic solvent derived from cellulose, making it a promising alternative to conventional organic solvents. High levels of monomer conversion and

polydispersity indices below 1.5 were achieved under ambient conditions, confirming the system's efficiency.

In this study, we investigated the Cu(0)-mediated polymerization of MMA in Cyrene®, focusing on the estimation of kinetic parameters based on experimental data generated in our laboratory. A mathematical model was developed using the well-established method of moments, allowing for simulation of the polymerization kinetics. The model showed strong agreement with experimental results, supporting its predictive capability.

This work contributes to the development of more sustainable polymer-manufacturing strategies and demonstrates the value of kinetic modeling as a tool for guiding the process optimization and industrial-scale implementation of green polymerization techniques.

2.56. Methanol Production via the Gasification of Waste Polyethylene: Simulation on Aspen Plus

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The production of methanol via the gasification of waste polyethylene offers a promising approach to plastic waste management and chemical production. This study utilizes Aspen Plus to simulate the gasification of waste polyethylene and subsequent methanol production. The simulation involves modeling the gasification reactor, the syngas treatment, and the methanol synthesis reactor. The effects of gasifier temperature, the steam-to-feed-mass ratio, and reactor pressure on methanol yield and purity are investigated. The results show that the Aspen Plus simulation accurately predicts the methanol production process, providing valuable insights into process optimization and design. The simulation results indicate that a gasifier temperature of 1000 °C, a steam-to-feed-mass ratio of 0.5, and a reactor pressure of 50 bar yield a methanol purity of 99%. This study also examines the economic viability of the process, including the costs of the feedstock, energy, and equipment. The results demonstrate that the production cost of methanol via the gasification of waste polyethylene is competitive with that of the traditional methods. This study provides a comprehensive framework for simulating and optimizing methanol production from waste polyethylene, offering a valuable tool for industry and research applications. This study's findings have significant implications for the development of sustainable waste management practices and the production of clean energy. Future research will focus on scaling up the process.

2.57. Multi-Criteria Decision Analysis-Supported Evaluation of Biowaste Anaerobic Digestion Options in Slovakia

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Anaerobic digestion is an effective and green alternative to treat various types of organic waste and to convert part of the feedstock into biogas that can be further treated to yield biomethane. Slovakia's biomethane production potential represents up to 10% of Slovakia's natural gas consumption and is largely unexploited to date. Batch or continuous-type reactors may be employed, in which organic substrates are transformed into biogas and digestate. Depending on feedstock properties, two technological approaches can be considered, differing in feedstock solids content: wet (below 15%) and dry (above 20%). The biogas produced consists (on a dry basis) largely of methane (~55% vol.), followed by carbon dioxide (~40% vol.), with nitrogen, oxygen, and hydrogen sulphide representing typical minor components and impurities. The aim of this paper is to develop a model of each available technology (continuous, dry batch, wet batch), as well as that of a biogas

treatment unit, and to evaluate the energetic, economic, and environmental potential of building a new anaerobic digestion plant in Slovakia, supplied by organic waste collected with a radius of 30 km. Feedstock composition and availability, energy integration, and product usability are evaluated. Multi-criteria decision analysis (MCDA) is applied to the considered plant configurations to identify the most viable and sustainable solution for anaerobic digestion plant application in Slovakia.

2.58. Multivariate Experimental Investigation of Impacts of Using Waste Glass on Physical and Mechanical Properties of Clayey Soil

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The use of waste materials to stabilize clayey soil could be a viable solution for soil stabilization, but a comprehensive investigation is required before it can be employed. This research aims to investigate the use of waste crushed glass powder as an additive in clayey soil, providing a comprehensive overview of its impacts on the physical and mechanical properties of the soil. This is undertaken by selecting different design mix percentages of clay soil, lime, and waste glass powder. The mix design samples are tested in laboratories using the relevant American Society for Testing and Materials (ASTM) standards, and the results are then analyzed. It was found through analysis that mixing 10% waste glass powder with 5% lime into clayey soil yields the most optimum results in terms of critical mechanical properties. With this combination, the unconfined compressive strength of the soil increased from 1.86 g/cm^2 to 2.51 g/cm^2, and the shear strength of the clayey soil increased from 0.93 g/cm^2 to 1.26 g/cm^2. The California Bearing Ratio (CBR) values did not show any sign of improvement, although the permeability coefficient (k) improved from 0.000072 cm/s to 0.000078 cm/s. On the other hand, no substantial change in the physical properties was observed with the addition of waste glass combined with lime. This research improves our understanding of the behavior of clayey soil reinforced with crushed glass powder; benefits future civil engineers who are studying soil stabilization; provides a way to reuse waste glass and reduce its environmental impact; and helps local communities with stable and more durable structures due to improved soil conditions.

2.59. Natural Zeolites Supported Green-Synthesized CeO_2@Polybenzimidazole Hybrid Materials for Dye Degradation

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Natural zeolites, clinoptilolite from the Golobradovo deposit, Bulgaria, and mordenite from the Lyaskovets deposit in Eastern Rhodopes, Bulgaria, were used for the preparation of natural-zeolite-supported CeO_2@Polybenzimidazole (PBI) hybrid materials with green-synthesized ceria incorporated using *Veronica officinalis* L. plant extract. In order to prepare hybrid composite powders of the natural zeolites/green-synthesized CeO_2, the surface was impregnated with the use of ethanolic KOH solution of meta-polybenzimidazole as dispersant media. The chemical and phase composition, structure, and thermal behavior of the obtained composite materials were investigated through X-ray fluorescence analyses, powder X-ray diffraction, Fourier-transform infrared spectroscopy, and thermogravimetric analysis. The presence of CeO_2 (33.1 mass % and 32 mass %) in the prepared clinoptilolite-

or mordenite-supported green-synthesized CeO_2@Polybenzimidazole was determined using X-ray fluorescence analysis. The photocatalytic properties of the synthesized hybrid materials were tested in the reaction of oxidative photocatalytic degradation of 5 ppm Reactive Black 5 (RB5) dye as a model pollutant under UV light irradiation. The photocatalytic results show that the RB5 dye demonstrates a higher degree of degradation (98%) with 120 min of UV irradiation in the presence of mordenite-supported/CeO_2@PBI as the photocatalyst compared to that with the clinoptilolite-supported/CeO_2@PBI (14%).

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2.60. Optimization of Green Ultrasound-Assisted Extraction of Phenolic Compounds from a Species of the Scrophulariaceae Family

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Ultrasound-Assisted Extraction (UAE) has emerged as a promising green technique for the efficient recovery of bioactive compounds from medicinal plants, due to its low energy consumption, reduced solvent use, and high extraction efficiency. In this study, UAE was applied to extract phenolic compounds from a medicinal plant species belonging to the Scrophulariaceae family. The influence of five key extraction parameters was investigated: ethanol concentration, extraction temperature, extraction time, solvent-to-solid ratio, and ultrasound power. A single-factor experimental approach was employed, where each parameter was varied individually while the others were kept constant, in order to assess its individual impact on total phenolic content (TPC). The Folin–Ciocalteu method was used to quantify TPC in the resulting extracts. The maximum TPC obtained for each parameter was as follows: 149.920 $\pm$ 3.12 μg GAE/mg dry extract at 60 °C, 52.601 $\pm$ 4.32 μg GAE/mg dry extract at 50% ethanol, 119.687 $\pm$ 1.09 μg GAE/mg dry extract at 100 min, 110.53 $\pm$ 1.14 μg GAE/mg dry extract at 60 mL/g, and 91.209 $\pm$ 2.67 μg GAE/mg dry extract at 60% ultrasound power. These values correspond to the highest TPC observed when each factor was optimized individually under fixed conditions for the others. Among all parameters tested, temperature exhibited the most significant impact on the extraction efficiency of phenolic compounds, while ultrasound power had a slight effect. Overall, this study confirms the potential of UAE as an environmentally friendly technique for the extraction of high-value phenolic compounds and highlights the importance of optimizing process parameters to improve extraction yield.

2.61. Optimizing Photovoltaic Parameters Using the Laguerre Method

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Photovoltaic (PV) energy has become a central pillar in the global transition toward clean and sustainable power sources, offering a renewable and environmentally friendly

alternative to conventional electricity generation. This study focuses on optimizing the parameters of a single-diode photovoltaic model to improve its accuracy in representing real-world behavior. A Laguerre-inspired optimization (LO) method is employed, which adjusts each parameter individually. The optimization process relies on minimizing the mean squared error (MSE) between the experimental current values and those predicted by the model, using the first and second derivatives of the objective function. The Laguerre approach's parameters are contrasted with those found in current research using analytical methods, iterative approaches, and metaheuristic algorithms. The root mean square error (RMSE), mean absolute error (MAE), and individual absolute error (IAE) are among the statistical error metrics that are computed to evaluate the performance of the suggested technique. The efficiency of the Laguerre technique in photovoltaic parameter extraction is demonstrated by this methodical approach, which enables perfect calibration of the model in line with experimental data. The suggested LO technique's robustness and dependability in this field are confirmed by the comparison study, which shows that the results produced by this approach have lower error rates than those obtained by other optimization methods.

2.62. Optimizing Tilt Angles: Enhancing PV Energy Output and Reducing Power Costs Across Diverse Climates

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The tilt angle of photovoltaic (PV) panels is a critical factor in maximizing energy yield and reducing power generation costs, particularly across diverse climate zones. This study presents an enhanced optimization approach for monthly tilt angle adjustments, integrating anisotropic solar radiation modeling with ambient temperature effects. Six geographically distinct locations were analyzed to determine the optimal monthly and annual tilt angles, which varied significantly—from as low as 1° to over 58°—based on latitude and seasonal conditions. Simulation results demonstrate that monthly tilt optimization increases the annual energy output by 8.8–9.9% compared to that under a fixed annual tilt configuration. Accounting for ambient temperature further improves energy gains and reduces the overall cost of power generation. The results emphasize that while monthly adjustments offer the greatest benefits, seasonal or biannual adjustments still capture a substantial portion of the performance improvement. In this research, the PV system's annual and monthly energy generation, as well as system losses, is also analyzed and discussed to provide a comprehensive performance evaluation. This study underscores the importance of climate-specific PV panel orientation strategies to optimize efficiency and cost effectiveness. The proposed methodology serves as a practical framework for both system designers and policymakers aiming to improve the performance of solar installations under varying environmental conditions. It supports smarter deployment of solar technologies, contributing to more resilient and economically sustainable energy systems.

2.63. Performance Evaluation of a Fixed-Bed Column Packed with Polylactic Acid and Treated Kaolin Adsorbents for the Removal of Fe and Cu from Abattoir Effluent

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Abattoir wastewater is a significant source of heavy metal contamination, posing a serious threat to water quality and public health. This study examines the performance of a laboratory-scale fixed-bed packed column designed for the removal of iron (Fe) and copper (Cu) ions using an innovative blend of polylactic acid (PLA) and kaolin clay treated with NaCl as adsorbents. The adsorbents were prepared via eco-friendly methods to enhance adsorption efficiency, mechanical strength, and sustainability. Column experiments were conducted under varying operational parameters, including a bed height of 5 to 10 cm, flow rate of 4 mL/min, and influent concentrations for Fe and Cu of 15.345 mg/L and 1.252 mg/L, respectively, to evaluate breakthrough curves and model the system. From the results obtained, the column demonstrated maximum adsorption performance at a bed height of 5 cm for Fe removal and 10 cm for Cu removal, with a flow rate of 4 mL/min. The PLA–kaolin hybrid demonstrated improved binding affinity, longer breakthrough time, and high affinity for Fe and Cu ions. Kinetic modeling confirmed the suitability of the Thomas model and Yoon–Nelson's models in predicting adsorption dynamics, with a good correlation ($R^2 > 0.95$), unlike the Adam–Bohart model. This work highlights the potential of bio-based polymer–clay adsorbents for low-cost, sustainable, and efficient treatment of industrial wastewater in fixed-bed systems.

2.64. Paint Microplastic Formation from Existing Structures

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Coil coatings are high-performance organic coatings used for many applications, primarily for exterior architecture such as facades, roofing, and rainwater systems. In this process, large metal coils (typically aluminum or steel) pass through a series of fully automated production lines. The applied organic coatings are generally thinner than post-applied paints but consist of multiple layers to prevent corrosion and enhance weather resistance and durability. A coating is composed of resins (polyesters, polyurethanes, etc.), pigments, solvents, and additives combined in various ratios. Normally, these materials are designed to withstand very harsh conditions. However, factors such as UV radiation, high humidity and temperature, prolonged exposure duration, and the chemical composition of both coating and substrate significantly influence their degradation.

Most studies place samples in artificial weathering chambers, which cannot fully replicate the complex interplay of environmental processes. As part of the degradation process, the formation of microplastics is expected. Paint particles are often overlooked or misclassified within the broader category of micro-debris. However, recent findings indicate that paint-derived particles can constitute a significant portion of microplastic pollution.

In this research, samples were collected from the external surface of an existing building made with coil-coated panels and analyzed in the laboratory. The techniques used for microplastic analysis were a stereomicroscope for optical observation, Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy for chemical analysis, and scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM–EDS) for elemental analysis and surface morphology characterization. This research aims to investigate the causes of microplastic formation, analyze their properties, and better understand their contribution to pollution, leading to the development of reduction strategies. Paint particles were detected in most collected samples, with spectroscopic analysis identifying many as polyester-based materials. A more systematic sampling approach is needed to determine all environmental processes affecting the degradation of existing structures.

2.65. Passives Cooling and Heating Strategies for Energy-Efficient Buildings: A Study for Sustainable Environmentally Friendly Green Design Processes

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Natural cooling and heating strategies have gained significant attention due to their ability to dissipate heat without electricity, particularly through radiative cooling (RC), especially in tropical climate areas, is essential in achieving sustainable and energy-efficient architecture. However, normal methods are often limited due to some environmental factors such as sunlight, rainfall and also snowfall constrained their effectiveness. To control these factors behaviour, we study about the thermal performance of two exterior wall materials—weather paint and red gutka bricks (Multani Tiles) during daytime or under high temperature through an integrated experimental and computational approach. The weather paint reflects almost 60–70% of sunlight depends upon their thickness and texture. Also, the red gutka bricks reduce temperature from 5–10 °C on similar properties. Experimental investigations include building-controlled sections of walls with both materials and capturing surface temperature variations using an infrared heat gun under different weather conditions. Simultaneously, four parametric building models have been developed in Revit, two for hot and two for cold climates, incorporating advanced passive design strategies such as optimized orientation, thermal mass integration, and adaptive insulation techniques. A comparative energy performance assessment is performed using Revit's simulation tools to assess the impact of wall material selection on thermal performance and indoor comfort levels. By combining experimental results with synthetic energy modelling data, this study offers a significant understanding of material efficacy in passive climate adaptation for sustainable environmentally friendly green practices aligned with climate-responsive design principles.

2.66. Phosphate Removal in a Pilot Filter System Using Sacha inchi Cuticle and Eggshells

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The presence of phosphates in wastewater is a growing concern worldwide, which is why there is currently interest in finding alternatives to remove them and avoid problems such as water eutrophication. Another important trend is the development of processes for utilizing agro-industrial waste to add value to production chains. In this sense, this work studied the removal of phosphates from water using an adsorbent composed of sacha inchi cuticle and eggshell in a 1:10 ratio, pyrolyzed at 400 °C for 20 min. For this, a filtration system was constructed using 10 cm diameter PVC pipes and employing 155.56 g of the adsorbent, which corresponded to a filtering medium volume of 1.3×10^{-3} m^3. With these design parameters, a working flow rate of 0.020 m^3/h and a filtration velocity of 2.52 m^3/m^2*h were established, which would correspond to a filter with an average velocity rate. To test the system, 8 L of a solution at a concentration of 133 mg/L of PO_4^{-3} was prepared. This solution was pumped through the filter using a submersible pump

of 25 W, taking samples while recovering 1, 1.5, and 5 L of filtrate, respectively. Subsequently, through spectrophotometric analysis, the removal of phosphates was quantified in duplicate. As a result, a PO_4^{-3} removal percentage of 35.58 ± 1.57% was obtained. It is relevant to note that the filtration time required to recover 5 L of filtrate was slightly more than 12 min. In conclusion, although the removal percentage is lower than that reported by other authors using similar materials as adsorbents, the difference is likely due to the conditions associated with the preparation of the adsorbent. Other conditions could be assessed to improve the removal percentage, contributing to the understanding of these residues and their valorization in the development of sustainable processes.

2.67. Photocatalytic Activity of $ZnFe_2O_4$ Nanoparticles for the Degradation of Fast Green FCF and Orange II Dyes

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Introduction: Synthetic dyes are extensively used in various industries. However, their persistence, toxicity, and resistance to biodegradation make them significant environmental pollutants, particularly in wastewater. Traditional treatment methods often fall short in completely removing such contaminants. In recent years, photocatalysis using semiconductor materials has emerged as a promising approach to dye degradation under mild conditions. Among various metal oxide photocatalysts, zinc ferrite ($ZnFe_2O_4$) has gained attention due to its narrow band gap, good stability, low cost, and activation under visible light.

Methods: $ZnFe_2O_4$ nanoparticles (NPs) were synthesized using a co-precipitation process and tested for photocatalytic effectiveness in degrading synthetic dyes under visible light. UV-Vis spectroscopy, Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) were used to confirm the structural, optical, and morphological features of the produced $ZnFe_2O_4$ sample. The photocatalytic activity was tested with Fast Green FCF and Orange II Sodium Salt, two common azo dyes.

Results: The spectrophotometric monitoring of dye degradation revealed that the produced material had significant photocatalytic efficacy. Under visible light irradiation for 90 min, the $ZnFe_2O_4$ NPs achieved 54% degradation of Fast Green FCF and 73% degradation of Orange II Sodium Salt.

Conclusion: This study emphasizes the benefits of utilizing $ZnFe_2O_4$ NPs as a visible-light-activated, cost-effective, and environmentally friendly photocatalyst. These findings add to the growing corpus of research aimed at establishing sustainable wastewater treatment options.

2.68. Photocatalytic Degradation of Ciprofloxacin Using Ultrasound-Assisted Synthesized Cu-Based Metal Organic Framework–Chitosan–Hydroxyapatite Catalyst

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This work investigates the development of copper-based metal organic framework (CuMOF)–chitosan (CS)–hydroxyapatite (HAp) hybrid catalysts to enhance the photocatalytic degradation of ciprofloxacin (CIP) in contaminated water. The integration of these materials resulted in a hybrid catalyst with exceptional photocatalytic activity, showing promise for addressing antibiotic-induced water pollution. Characterization techniques like Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), Fourier Transform Infrared Spectroscopy (FTIR), and X-ray Diffraction (XRD) confirmed that ultrasound-assisted synthesis improved the physicochemical properties of the catalyst, including higher surface area, better morphology, and greater structural stability. Photocatalytic tests demonstrated that both conventional and ultrasound-assisted catalysts effectively degraded CIP, with the latter achieving an 83.49% degradation rate at 1 g catalyst loading after 120 min of exposure, particularly at lower initial CIP concentrations. Increasing the catalyst loading from 0.5 g to 1.0 g provided more active sites, accelerating pollutant breakdown. Key factors such as catalyst loading, pollutant concentration, and exposure time were identified as critical to the degradation process, with statistical analysis underscoring the importance of optimizing these variables for maximum efficiency. The study highlights the potential of CuMOF-CS-HAp hybrid catalysts in environmental remediation, particularly for tackling antibiotic pollution in aquatic environments. It also emphasizes the role of ultrasound-assisted synthesis in boosting photocatalytic performance, contributing to the development of advanced materials for water purification.

2.69. Post-Synthetic Modification of Bimetallic Zn/Mg-Metal–Organic Framework-74 for Enhanced Carbon Capture Efficacy

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The increasing concentration of carbon dioxide (CO_2) in the atmosphere, largely driven by fossil fuel combustion, necessitates the development of advanced nanomaterials for carbon capture. Metal–organic frameworks (MOFs) have emerged as alternative carbon capture materials due to their porosity and high surface area in contrast to poorly performing conventional methods. However, MOF-74's performance is limited by moisture sensitivity and inadequate uptake when engaging with low CO_2 partial pressures. This study focuses on the synthesis and post-synthetic modification of a bimetallic $Zn_{0.75}Mg_{0.25}$-MOF-74 to overcome these limitations. The MOF was synthesized using a solvothermal method with terephthalic acid as the organic linker. The effects of varying temperature (100–150 °C) and reaction time (12 h–48 h) were optimized using a central composite surface response approach. Post-synthetic functionalization with ethylenediamine (ED) was carried out to enhance adsorption affinity and moisture resistance. The physicochemical characteristics of the material were evaluated using XRD, SEM, FTIR, BET, and TGA techniques. It is expected that CO_2 uptake is increased after ED functionalization as the introduced amine groups form stronger interactions with CO_2. The N-H bending and stretching bands indicative of amine incorporation are expected through FTIR analysis, with preserved COO^- stretching vibrations, and C=O, C-O, Mg-O and Zn-O vibrations confirming retention of the MOF framework. The XRD patterns should maintain the characteristic peaks of MOF-74, indicating preserved crystallinity. The SEM micrographs are expected to show an uncompromised morphology, with a marginal decrease in BET surface area due to amine pore occupation. Finally, the TGA is expected to reflect enhanced thermal stability.

These findings will present ED-functionalized Zn/Mg-MOF-74 as a potential candidate for scalable, sustainable and efficient CO_2 capture under real-world flue gas conditions.

2.70. Precision Eggshell Valorization: Optimizing Biomaterial Production with NIR/HSI and Machine Learning

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Introduction: The substantial global generation of eggshell waste, estimated at millions of metric tons annually, presents a significant environmental challenge, contributing to landfill burden and associated pollution. This necessitates innovative strategies for waste valorization, transforming this abundant byproduct into high-value biomaterials.

Methods: The valorization process involves initial cleaning and drying of eggshells to remove organic contaminants and moisture. Subsequently, eggshells undergo mechanical processing (crushing, grinding, sieving) to achieve desired particle sizes, and thermal treatments like calcination to convert calcium carbonate into calcium oxide or hydroxyapatite precursors. For real-time process control and quality assurance, advanced non-destructive analytical techniques such as Near-Infrared (NIR) spectroscopy and Hyperspectral Imaging (HSI) are integrated. These optical methods, coupled with machine learning algorithms, enable rapid and accurate assessment of critical parameters including chemical composition, moisture content, and purity, ensuring optimal material characteristics for specific applications.

Results: The application of these controlled processes, rigorously monitored by NIR/HSI and machine learning, yields high-purity eggshell-derived biomaterials. These materials find diverse applications, including advanced bone regeneration scaffolds and dental implants in biomedical engineering, natural exfoliants and skin mineralizers in cosmetics, calcium fortification in food and nutraceuticals, and adsorbents for environmental remediation.

Conclusions: Eggshell valorization represents a compelling example of circular economy principles in action, transforming a low-value waste stream into high-value products. The integration of advanced analytical techniques like NIR spectroscopy and HSI, powered by machine learning, is pivotal for ensuring the quality, consistency, and safety of these biomaterials, thereby facilitating their broader commercialization and contributing to a more sustainable future.

2.71. Prediction and Optimisation of Cr (VI) Removal by Green and Biodegradable Adsorbent from Aqueous Solution Using Deep Machine Learning (ANN and ANFIS)

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This investigation aims to assess the performance of a green adsorbent in a laboratory-scale reactor for removing chromium (VI) from wastewater. Cellulose nanocrystals are excellent materials for removing heavy metal ions because of their biodegradability, availability and adaptability in dynamic and static adsorption processes. The green adsorbent was characterised using FTIR and SEM. A deep machine learning approach (artificial neural network and adaptive neuro-fuzzy inference system) was used to forecast the adsorption capacity of green and biodegradable adsorbent to remove chromium (VI) from

wastewater. Four operational variables were input: pH, starting concentration of Cr (VI), contact duration, adsorbent dose, and the adsorption capacity output. The network was trained using feedforward propagation using the Levenberg–Marquardt algorithm (LM). ANN models with three algorithms (purelin, logsig, and transig) and ANFIS models were tested to optimise, develop, and forecast the chromium (VI) adsorption using a green and biodegradable adsorbent. The optimum conditions were pH 6, concentration 50 mg/L, time 120 min, and adsorbent dosage 10 g/100 mL. The findings show that artificial neural network models effectively predict chromium (VI) adsorption. In the training dataset, R^2 was 0.979, Mean Square Error (MSE), absolute average relative error (AARE) was 0.053, root mean square error (RMSE) was 0.077, and absolute average relative error (AARE) was 0.053 for the artificial neural network. For the adaptive neuro-fuzzy system, an RMSE of 0.021, AARE of 0.015, ARE of 0.01, MSE of 0.017, and R^2 of 0.998 were obtained.

2.72. Prediction of Microbial Dynamics During Grape Pomace Composting Using NIR Spectroscopy and ANN Modeling

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The composting of grape pomace represents an environmentally sustainable method for valorizing agro-industrial waste by converting it into nutrient-rich organic fertilizer. This study aimed to develop robust predictive models for monitoring microbial population dynamics during composting using near-infrared (NIR) spectroscopy as a rapid, non-destructive analytical tool. A total of nine composting experiments were carried out in laboratory-scale reactors (V = 5 L) over a 30-day period, with the initial substrate moisture content ranging from 50% to 65% and the air flow rates ranging from 0.35 to 2.00 L/min. NIR spectra were recorded within the 904–1699 nm range using an NIR-128-1.7-USB/6.25/50 μm spectrometer. Artificial Neural Network (ANN) models were developed to correlate spectral data with microbiological parameters, including bacterial, fungal, and total microorganism counts. Among various spectral preprocessing techniques, smoothing was identified as the most effective for predicting bacterial counts, yielding the highest Residual-Error-of-Prediction-to-Standard-Deviation ratio (RER = 10.083). In contrast, the combination of the second-order Savitzky–Golay derivative followed by multiplicative scatter correction (SG2D + MSC) proved optimal for modeling fungal (RER = 15.075) and total microorganism counts (RER = 12.040). The use of NIR spectroscopy offers several advantages, including minimal sample preparation, rapid data acquisition, the ability to analyze samples in situ, and simultaneous monitoring of multiple compost parameters. Combined with ANN modeling, this approach enables real-time, accurate prediction of compost microbiology, offering significant potential for process optimization. These findings demonstrate the value of integrating NIR and machine learning tools in advancing sustainable and efficient composting practices.

2.73. Predictive Modeling of Solar PV Output Under Seasonal Weather Variability Using Machine Learning

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Machine learning models offer dynamic systems that can surpass the limits of quantitative models for estimating solar photovoltaic (PV) output, particularly under changing seasonal weather conditions. This study evaluates data-driven models, such as linear

regression (LR), decision trees (DTs), and artificial neural networks (ANNs), to determine solar energy production. Historical metadata from May 2024 to December 2025 utilized as the input data pertained to climatic factors such as sun irradiance, temperature, humidity, wind speed, cloud cover, and precipitation. The ML systems were trained and validated in MATLAB, with integrated hyperparameter adjustment to enhance the model performance. Quantitative indicators comprising the mean squared error (MAE), root mean square error (RMSE), and coefficient of determination (R^2) were applied to validate and compare the generalizability of the resultant models. The ANN model surpassed LR and the DT in identifying nonlinear relationships, with an average performance of an MSE = 0.7512, an RMSE = 0.8667, and R^2 = 0.9725. This was achieved on an optimized ANN architecture using the Bayesian Regularization training methodology, one hidden layer with eight neurons, a sigmoid activation function, and a learning rate of 0.001. These results demonstrate that the ANN provides a more efficient strategy for reliable PV output estimation, vital to improving energy planning and facilitating the larger integration of solar technology into weather-dependent power networks.

2.74. Predictive Modelling of Polyphenol Concentration After Sequencing Batch Reactor Winery Wastewater Treatment

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The treatment of winery wastewater (WWW) is crucial for surface water protection and/or enabling water reuse. While biological treatment offers a flexible and cost-effective approach, monitoring and process control remain quite complex. Machine learning (ML) models have gained attention as effective tools to address these challenges. However, extensive operational data from such systems is inherently limited; monitoring specific recalcitrant compounds (e.g., polyphenols) is time-consuming and costly due to complex analytical methodologies and chemical reagent disposal. This study aimed to develop and evaluate ML models to predict polyphenol concentration after biological treatment using a small and high-dimensional dataset. A Sequencing Batch Reactor (SBR), fed with WWW, was monitored for 140 days, generating a small yet comprehensive dataset (38 features and 36 observations) that captured different operational conditions. These features served as input to predict polyphenol concentration (target). Three ML algorithms were evaluated: ElasticNet (EN), Support Vector Regression (SVR) and Multi-Layer Perceptron Regressor (MLPR). To maximize training data and ensure robust evaluation given the limited dataset, Leave-One-Out Cross-Validation (LOOCV) was used for model performance assessment. Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) were employed as evaluation metrics. For models with default parameters, the EN model demonstrated the best initial predictive capacity for polyphenol concentration (MAE: 1.08 $\pm$ 0.94 mg/L; MAPE: 11.7 $\pm$ 12.5%). However, after feature selection and hyperparameter tuning, the SVR model achieved superior predictive capability (MAE: 0.88 $\pm$ 0.68 mg/L; MAPE: 9.3 $\pm$ 8.3%) via LOOCV. This study established a robust SVR predictive model for polyphenol concentration in SBR winery wastewater treatment. Despite the small dataset, LOOCV, feature selection and hyperparameter tuning ensured the development of a robust model with promising performance and generalization. This predictive tool offers significant potential for real-time monitoring, SBR optimization, and enhancing polyphenol removal, contributing to environmental sustainability in winery wastewater.

2.75. Preliminary Evaluation of the Use of Grape Pomace in the Formulation of Vegan Chorizo

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This preliminary study aims to implement circular economy concepts by reusing agro-industrial waste, such as grape pomace, for sustainable food production. It focuses on creating regional formulations to enhance local economies and biodiversity. The research investigates how grape pomace affects the colour of vegan sausages through colourimetry while promoting local companies to adopt circular practices that reduce waste and optimize resource use in sausage production and consumption. Three vegan sausage formulations were developed containing different proportions of grape pomace (F1 = 10, F2 = 20, and F3 = 30%) and a control with linseed flour (C) (100%). Instrumental colour analysis revealed marked differences between the vegan formulations and the traditional control. The control sample (C) had an L* value of 40.81, which was significantly higher than the vegan formulations F1 (L* = 16.22), F2 (L* = 15.49), and F3 (L* = 14.18). The samples containing grape pomace were visibly darker in colour (lower L* values), which can be attributed to the presence of phenolic compounds naturally present in pomace, such as anthocyanins and tannins. These compounds, in addition to contributing to the dark colour, can also confer functional characteristics to the product. There was a significant reduction in the a* (red) parameter in the vegan formulations (F1 = 4.79, F2 = 4.09, and F3 = 3.89), reflecting the absence of myoglobin, a typical pigment in meat products, and indicating a different colour profile. The b* (yellow) component was also lower in the pomace formulations (F1 = 4.95; F2 = 2.11; F3 = 1.29) compared to the flaxseed control (C = 23.04), reinforcing the tendency towards more opaque and neutral tones. Although different from traditional sausages, these visual changes may appeal to consumers who prefer natural and sustainable products. Grape pomace shows promise as an ingredient in vegan sausage formulations, offering nutritional value and supporting sustainability by reusing agro-industrial by-products.

2.76. Python-Powered Optimization of Sustainable 1,3-Butadiene Production from Ethanol: Bridging Thermodynamics, Kinetics, and Machine Learning

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This study pioneers a novel Python-based computational framework to optimize the sustainable production of 1,3-butadiene (BD) from bioethanol. The core innovation lies in the synergistic integration of kinetic modeling, thermodynamics, and machine learning (ML) with an optimized K_2O:ZrO_2:ZnO/MgO-SiO_2 catalyst. This catalyst was selected for delivering the highest combined BD and acetaldehyde selectivity (72 mol%) while maintaining reasonable BD yield and productivity (0.12 $g_{BD} \cdot g_{cat}^{-1} \cdot h^{-1}$), outperforming Na and Li analogues primarily due to better surface area retention, thereby enhancing BD selectivity and minimizing byproducts. This holistic approach elucidates how temperature (300–400 °C), weight hourly space velocity (WHSV: 0.3–2.5 h^{-1}), and ethanol feed fraction (0.41–0.85) govern process efficiency. Key findings confirm the reaction's endothermic

nature and a strong correlation between thermodynamic driving forces (Gibbs free energy $\Delta G = -25.3$ to -10.5 kJ·mol^{-1}) and productivity. Optimal conditions (350–375 °C, WHSV 0.93–1.24 h^{-1}) maximized BD yield at 25.3%, significantly reducing byproducts compared to non-optimal settings where acetaldehyde selectivity reached 57.3%. Among ML models, Random Forest excelled ($R^2 = 0.91$ for ethanol conversion prediction), attributed to its superior handling of complex, nonlinear variable interactions, with temperature and feedstock composition identified as dominant factors. The methodology provides a practical computational toolkit for catalyst and reactor design, explicitly addressing the critical trade-off between productivity (reaching 0.49 $g_{BD} \cdot g_{cat}{}^{-1} \cdot h^{-1}$ at high WHSV) and yield. By enabling data-driven optimization of feed control and catalyst efficiency, this work offers a powerful strategy for advancing renewable chemical manufacturing and decarbonizing the production of critical precursors such as BD for synthetic rubber and plastics.

2.77. Real-Time Adaptive Energy Management in Renewable Energy Communities: Reducing the Challenge of Forecasting and Prior Knowledge Dependencies

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The integration of renewable energy (RE) sources and the increasing complexity of energy management (EM) systems have resulted in considerable advances in energy usage optimization in smart renewable energy communities (RECs). Existing methods rely on forecasting techniques that necessitate accurate projections of future energy prices, RE generation, user comfort, and behavior. While these strategies are effective in controlled contexts, they have limitations in dynamic, real-time scenarios where system inputs fluctuate unexpectedly. Using prior knowledge or forecasts might result in computational cost in real-time energy optimization. This study proposes a novel approach to real-time adaptive EM in RECs that overcomes the need for prior knowledge and the overhead of forecasting future buildings' EM systems. To tackle the uncertainties in system input dynamics (i.e., RE generation process, battery storage, load arrival processes, demand, and dynamic pricing), this study presents a one-slot-look-ahead queue-based Lyapunov optimization framework. This approach allows for real-time EM systems and reduces user discomfort in smart buildings that are linked and connected to the smart grid. The main goal is to reduce the average running costs (of procurement and operations) by optimizing the real-time scheduling of both electrical/thermal loads and electrical/thermal storage systems, managing their degradation and life cycle, and ensuring indoor user comfort. The optimization challenge is reduced to smaller sub-problems that can be solved one after the other in real time and are asymptotically optimal. They are particularly effective for real-time use in REC settings, especially when the input statistics are either unknown or highly variable. Simulation results under different scenarios and weather conditions, on both a daily and a monthly basis, indicate that the proposed method leads to average reductions in daily and monthly running costs of up to 13.53% and 19.37%, respectively, when benchmarked against other recent research, which reports similar decreases in the same scenarios.

2.78. Real-Time Pollutant Forecasting Using Edge AI Fusion in Wastewater Treatment Facilities

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Wastewater treatment is one of the major challenges in the reuse of water as a natural resource. Cleaning of water depends on analysing and treating the water for the pollutants that have a significant impact on the quality of the water. Detecting and analysing the surges of these pollutants well before the recycling process is needed to make intelligent decisions for water cleaning. The dynamic changes in pollutants need constant monitoring and effective planning with appropriate treatment strategies. We propose an edge computing-based smart framework that captures data from sensors including ultraviolet, electrochemical, microfluidic and other significant sensor streams. The edge devices send the data from the cluster of sensors to a centralized server that segments anomalies, analyses the data and suggests the treatment plan that is required, which includes aeration, dosing adjustments and other treatment plans. A logic layer is designed at the server level to process the realtime data from the sensor clusters and identifies the discharge of nutrients, metals and emerging contaminants in the water that affects the quality. The platform can make decisions on water treatments using its monitoring, prediction, diagnosis and mitigation measures in a feedback loop. A rule-based Large Language Model (LLM) agent is attached to the server to evaluate data and trigger required actions. A streamlined data pipeline is used to harmonise sensor intervals, flag calibration drift, and store curated features in a local time-series database to run ad-hoc analyses even during critical conditions. An user dashboard has also been designed as part of the system to show the recommendations and actions taken. The proposed system acts as an AI enabled system that makes smart decisions on water treatment, providing an effective cleaning process to improve sustainability.

2.79. Recovery of Spent Battery Materials for Reuse in Energy Storage Applications

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The rapid expansion of electric vehicles and renewable energy systems has led to a surge in demand for lithium-ion batteries, raising urgent concerns over raw material scarcity, environmental impact, and end-of-life waste. Necessity of finding sustainable processes for the battery recycling, implementation of recovered materials in the battery loop and reuse of battery components in second-life applications are crucial topics in securing the energy sector for the coming years. This presentation explores the recovery of critical battery components from spent battery cells, with a focus on methods that enable their reuse in energy storage applications.

In our work, we evaluate hydrometallurgical approaches, such as leaching and electrochemical methods of Li-ion and alkaline batteries, to recover valuable resources for their further reuse in battery applications. Emphasis is placed on critical aspects in the recycling technology, such as scalable, low-impact recycling methods that preserve material integrity and performance. We explore the electrochemical behavior of the used batteries under varied conditions, with implementation of bio-based materials and advanced electrochemical techniques to investigate their reuse in novel batteries and secondary-life applications. By

aligning material recovery with battery manufacturing needs, this work underscores the potential for a circular economy in battery technology, reducing dependence on natural resources and waste recovery while supporting sustainable energy goals.

2.80. Reducing and Eliminating Flare in Marmul Field

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The objective of this project is to eliminate permanent flaring and provide a sink for associated gas from the Main Marmul Production Station (MMPS) bulk separators (approximately 210,000 sm^3/d), which is currently supplied to Marmul Power Station.

The associated gas from MMPS, with an H2S level of ~690 ppmv, is compressed and sent as export gas to Marmul Power Station, Marmul-A station, a water treatment plant (WTP), and Qaharir and Thuleilat stations. The high-H2S flash gas from the MMPS tanks is currently flared via the Gas Recovery Compressor (GRC) K-2412 to prevent contamination of the MMPS gas system. This is necessary due to the incompatibility of the power plant with sour gas.

Marmul Power Station, nearing the end of its design life, is planned for retirement starting in Q2 2022. After its closure, there will be no route for evacuating MMPS export gas.

To address this, associated gas from production separators will be mixed with high-H2S flash gas recovered from various tanks via a new Gas Recovery System. The combined gas will be treated in the Gas Sweetening Unit (GSU) using Thiopaq Technology. The sweet gas will be compressed, dehydrated, and sent to the South Oman Gas Line (SOGL).

Condensate from the new facility will be stabilized in a new Condensate Stabilizer Unit (CSU) before being routed to the MOL pump suction. Off-gas from the CSU and the condensate flash vessel will be routed to existing fired heaters for fuel gas use. Excess gas will be routed to the flare and managed under the separate "MMPS Excess Flare Gas Recovery Project".

The project will also include utilities such as an instrument air system, nitrogen generation, and flare system rationalization.

2.81. Removal of Fine Particles from Water Using Plant-Based Microfoams

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The persistent challenge of removing fine particles from wastewater necessitates the development of environmentally sustainable and efficient treatment technologies. This study explores the application of micro-foam bubbles, also known as Colloidal Gas Aphrons (CGAs), made from plant-based surfactants on fine particle separation from wastewater. The performance of plant-based surfactants (Soapnut and Shikakai) was compared with that of a synthetic surfactant (Sodium Dodecyl Sulphate) in terms of flotation efficiency, foam stability, and water quality improvement. A series of experiments assessed the influence of the surfactant type, foam-to-feed ratio, solution pH, and column height on CGAs' performance. The results showed that SDS produced the highest average removal efficiency across all particle types (49.59%), followed by Soapnut (48.95%) and Shikakai (43.64%). However, Shikakai displayed superior removal performance for specific contaminants such as kaolinite and algae under certain conditions. The optimal foam-to-feed ratio was found

to be 1.0 for SDS (60.59% removal), 0.5 for Shikakai (38.61%), and 0.1 for Soapnut (32.06%). Foam stability, a critical factor in flotation efficiency, varied significantly with the pH and surfactant type. Quantitative analysis revealed a strong negative correlation between foam stability and removal efficiency for Soapnut ($r = -0.79$) and Shikakai ($r = -0.76$), as well as a moderate positive correlation for SDS ($r = 0.47$). Additionally, the effect of column height on flotation efficiency confirmed that moderate sampling port heights (45–60 cm) provided optimal removal efficiencies due to enhanced contact time. This study demonstrates the potential of sustainable use of plant-based surfactants in CGA-based flotation and provides insights into optimising flotation parameters, thereby contributing towards greener water treatment processes.

2.82. Risk Analysis of Green Hydrogen Storage Systems Using Fault Tree and Bayesian Network

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Hydrogen is increasingly recognised as a key element in the global transition towards sustainable and clean energy, offering a promising alternative to fossil fuels. Its production from renewable sources via electrolysis aligns with the goals of reducing carbon emissions and achieving energy security. However, despite its advantages, hydrogen poses significant challenges, particularly in terms of safe and efficient storage. Due to its low molecular weight, high diffusivity, and extreme flammability, hydrogen storage systems require rigorous risk assessment to prevent accidents and ensure operational reliability. This study focuses on evaluating the unavailability and safety of green hydrogen storage systems using two well-established risk analysis methods: Fault Tree Analysis (FTA) and Bayesian Networks (BNs). These complementary approaches enable the identification of critical failure modes and the quantification of system reliability under various scenarios. The comparative analysis reveals that both methods yield nearly identical results, underscoring the robustness and validity of the risk assessment. Based on these findings, the study proposes targeted safety measures aimed at mitigating identified risks and enhancing the secure deployment of hydrogen storage infrastructure. Ultimately, this work contributes to the advancement of safer hydrogen technologies and supports the broader energy transition by addressing key safety concerns associated with green hydrogen storage.

2.83. Screening of Raw Materials from Agricultural and Forestry Activities for Application in the Removal of Dyes from Water

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The presented work was motivated by the search for a low-cost and efficient adsorbent for dye removal from wastewater [1]. Raw materials from agricultural and forestry activities, such as coconut shells, olive stones, almond shells, and cork residues, were used, as collected from the field, for dye removal from wastewater. These raw materials also served as precursors for the production of activated carbon (ACs), using KOH as an activating agent, at 973 K. The adsorbents were characterized physically and texturally. It was observed that natural adsorbents have lower carbon content, surface area, and porous volume and higher acidic surfaces than their respective ACs.

Although ACs in general have superior performance in removing pollutants (dyes, pesticides, drugs) when compared to their precursors, to improve the properties of ACs and their performance in methylene blue (MB) removal from water, these were subjected to a modification process involving the introduction of nitrogen into their matrix during the activation procedure.

Screening a diversity of low-cost, available raw materials allows for the identification of those that present a high adsorption capacity, directly or after being converted into ACs, for MB removal from water. These were proposed for use in pollutant removal from water used for human consumption, especially in developing countries, where wastewater is taken from lakes, wells, and rivers and consumed without any previous treatment. This work allows us to valorize subproducts from agricultural and forestry activities, removing them from landfills and obtaining adsorbent materials that are successfully used in the treatment of water that can even be used for consumption, thus closing the cycle of the circular economy.

[1] Cansado, I.P.P., Geraldo, P.F., Mourão, P.A.M., Castanheiro, J.E., Carreiro, E.P., and Suhas. Utilization of Biomass Waste at Water Treatment. *Resources*, vol. 13, no. 3, Mar. 2024, doi: 10.3390/resources13030037.

2.84. Simulation of Green Diesel Production Through Hydrotreatment of Waste Vegetable Oil

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Due to the world's increasing demand for energy and high reliance on fossil fuels to produce it, there has been an urgent need to explore alternative ways to produce cleaner energy. Green diesel produced from renewable resources, such as waste vegetable oil, is a promising alternative due to its compatibility with petroleum diesel produced from fossil fuels. This study investigated the simulation of the hydrotreatment process of waste vegetable oil (WVO) to produce green diesel. ChemCAD version 8 was used to develop the simulation, and a kinetic model based on the Langmuir–Hinshelwood mechanism (an LH-C-ND model) was developed, where fatty acids such as oleic, stearic, and palmitic acid in WVO are converted into long-chain hydrocarbons (C15, C16, C17, and C18). The effect of the process parameters on the green diesel yield was assessed at different temperatures, pressures, and H2/oil ratios. The optimal conditions for green diesel production were identified as a temperature of 275 °C and a pressure of 30 bar, with an H_2/oil ratio of 0.33. Optimisation efforts focused on minimising the formation of CO_2, CO, and water. In these operating conditions, a high green diesel yield was achieved, with the conversion of WVO exceeding 90%, and over 80% of the products were useful for green diesel. This study contributes to Sustainable Development Goal (SDG) 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all by exploring the production of cleaner energy alternatives like green diesel from waste vegetable oil. It is recommended to recycle unreacted hydrogen to increase the efficiency and lower operational costs, as well as to conduct a life cycle assessment to evaluate the overall environmental impact.

2.85. Study of In-Situ Phytoremediation of Diesel-Contaminated Soil with Varying Soil Compositions and the Influence of NPK Fertiliser

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This study investigates the effectiveness of phytoremediation for diesel-contaminated soil using rye grass and fescue grass in both controlled and natural conditions. The research examined plant performance across various soil compositions (100% topsoil, 50:50 soil-sand mixture, and 25:75 soil-sand mixture) with differing diesel oil concentrations (10, 15, and 20 mL/kg) and NPK fertiliser treatments (5, 10, and 15 g/kg). The experiment was carried out in two phases: an initial 7-day period under controlled laboratory conditions, followed by a 3-month period in natural outdoor conditions (July to October) to simulate real-world applications. During the outdoor phase, plants were exposed to typical Scottish weather, with average temperatures ranging from 17 °C (July–August) to 13 °C (October), and atmospheric pressure fluctuating between 980 and 1040 hPa. Initial experiments demonstrated that while both grass species exhibited resilience in contaminated environments, optimal growth occurred in 100% topsoil and 50:50 soil-sand mixtures, with minimal to no growth in 75% sand compositions. Oil concentration after phytoremediation was measured using UV spectrophotometry at a 306 nm wavelength and converted using the calibration curve equation Y = 0.5731x (where Y is absorbance and x is oil concentration percentage), revealing varying effectiveness across soil compositions. Results indicated significantly lower remaining oil concentrations in 25% soil mixtures compared to 100% soil samples, primarily due to higher soil permeability in sand-mixed samples. For both grass types, the remaining oil concentration ranged from approximately 0.2% to 1.2% wt/wt across different initial contamination levels, with both rye and fescue grass demonstrating comparable remediation capabilities. The addition of NPK fertiliser showed promising results in enhancing plant growth and potential remediation capabilities. This research contributes to an understanding of the practical applications of phytoremediation, particularly focusing on the role of soil composition and nutrient supplementation in plant survival and diesel concentration reduction under both controlled and natural conditions.

2.86. Study on Suppression of Hydrogen Generation by Using Heated Simulated Incineration Ash and Water Simulating an Ash Conveyor Environment

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Incidents of explosions in ash treatment facilities at waste incineration plants have been reported. The cause is believed to be the reaction between cooling water and metallic aluminum contained in the ash, which generates hydrogen gas.

The authors have been investigating methods to suppress hydrogen generation through temperature changes during the conveyor transport process of ash treatment equipment. In this study, to replicate the temperature changes during conveyor transport, an experiment was conducted in which heated simulated incineration ash was immersed in water within a container for cooling. After cooling, the simulated ash was removed from the water, and the hydrogen gas concentration around the simulated ash was measured. The simulated incineration ash was composed of a mixture of aluminum powder, alumina powder, calcium oxide powder, and silicon dioxide powder, which are the main components of incineration ash.

The experimental results showed that as the temperature of the water during immersion increased, the amount of hydrogen gas generated during immersion decreased, and the hydrogen gas concentration around the simulated ash also decreased.

Based on these results, it was found that by maintaining the high-temperature incineration ash discharged from the furnace and the cooling water above 70 °C and allowing natural cooling during transport on the conveyor, it may be possible to suppress hydrogen explosions in the conveyor and ash pit.

2.87. Study on the Effect of Reactor Scale on Hydrogen Generation from Aluminum Powder and Water via Stirring

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Hydrogen is considered a promising solution for mitigating global warming due to its potential to provide CO_2-free power when used in fuel cells and power generation systems. Traditionally, hydrogen production relies heavily on fossil fuel reforming, which emits CO_2. This study investigates an alternative hydrogen generation method by stirring aluminum alloy powder in water. The aluminum alloy powder is derived from waste aluminum, and the process is powered by renewable energy, aiming to combine waste recycling with carbon-neutral hydrogen production. This approach explores the feasibility of establishing a sustainable hydrogen production plant.

Previous experiments using a small stirred reactor (100 mL) compared pure aluminum powder with Al-Sn alloy powders. The alloy powders produced significantly more hydrogen, likely because stirring causes particle fragmentation, increasing the powders' specific surface area and enhancing the reaction rate.

To assess scalability for industrial application, experiments were conducted in a larger 500 mL reactor. Hydrogen generation was tested with pure aluminum and Al-Sn alloy powders of varying compositions. The results demonstrated that hydrogen production using alloy powders in the larger reactor was six times greater than in the smaller reactor—exceeding the expected increase based on volume scaling alone. This discrepancy was attributed to the increased power input from the stirrer in the larger reactor, which likely intensified particle fragmentation and reaction kinetics.

These findings offer valuable insights into the scale-dependent behavior of the reaction system, providing essential data for the design and practical implementation of a hydrogen production plant based on this stirring-induced aluminum–water reaction method.

2.88. Sustainable Desalination Using Activated Carbon Biofilters from Orange Peels and Banana Stems

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Scarcity of water is still the most critical issue facing the world today. It is further compounded by high population growth, pollution, and climate change. Traditional means of desalination are effective but tend to be energy-intensive, resource-expensive, and environmentally demanding. This research explores a novel, environmentally friendly method of seawater desalination in the creation of low-cost biofilters made from crop waste. Banana plant stems and orange peels were transformed into powdered and activated carbon

forms and blended into polyurethane foam matrices to achieve bioadsorptive filters. The materials were examined through pH analysis, granulometry, ash content, zeta potential, and FTIR spectroscopy to identify their physicochemical properties. Experimental tests yielded impressive improvements in adsorption capacity, with orange-peel-filter-activated samples recording a 31.5% particle size reduction and up to 72% removal of copper (Cu^{2+}) and 68% removal of cadmium (Cd^{2+}) under optimized conditions. A portable appliance, the "Magique Cup," was also introduced in this study, which can be applied in homes for water treatment using filters. Regeneration tests also indicated that up to 85% of the original adsorption capacity could be recovered through acid or heat treatment. The findings show the potential of biodegradable, waste-derived biofilters to provide successful alternatives to traditional desalination processes. Scaling of the technology, long-term filter stability, and field-operating performance should be tackled in subsequent research.

2.89. Sustainable Treatment of Toxic Leachate: Removal of Cadmium and Lead from Payatas Dumpsite Using Electrocoagulation

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This research examines the effect of using electrocoagulation as a means of treating the lead and cadmium content in the Payatas leachate using aluminum electrodes. The Payatas leachate is a threat to the environment and the health of the people residing near the facility. Three factors (initial pH, voltage, and time) are analyzed to determine the most effective treatment condition that would ensure the heavy metal content remains within the minimum standards of DAO Class C water effluent. The experimental factors are varied based on the following: initial pH (5, 8, and 11), applied voltage (4.0 V, 6.0 V, 8.0 V), and electrocoagulation (EC) time (30 min, 60 min, 90 min). The initial and final metal concentrations are determined with the help of inductively coupled plasma optical emission spectroscopy (ICP-OES). The results showed that the optimized values of the parameters based on the percent reduction of cadmium and lead content are pH 8, 8.0 V at 90 min, and pH 5, 6.0 V at 30 min, respectively. From an economic perspective, the cost-effectiveness of the process is assessed based on the energy consumption in terms of the total cost of electricity used. Based on the economic evaluation, the most effective setting for the electrocoagulation process is pH 11, 6.0 V at 90 min, and pH 8, 4.0 V, at 30 min for cadmium and lead, respectively. This work elucidated the potential of the electrocoagulation process as an alternative technique for the treatment of toxic leachate from the Payatas dumpsite. The sustainability of the process can be improved further through the integration of a renewable energy source into the EC system.

2.90. Synthesis of Calcium Vanadate Nanoparticles as a Catalyst for Dry Sulphur Dioxide Desulfurization

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Chronic health and ecological issues stemming from sulfur dioxide (SO_2) emissions due to fossil fuel combustion necessitate the development of more efficient and cost-effective scrubbing methods beyond conventional wet flue gas desulfurization (WFGD). This study explored the synthesis of a calcium vanadium-based nanocomposite (CaV_2O_6) using vanadium pentoxide (V_2O_5) waste and calcium nitrate ($Ca(NO_3)_2$) as precursors, intended for application as a catalytic adsorbent in dry desulfurization systems. The primary objective was to enhance SO_2 selectivity and catalytic activity by refining the sorbent's morphological properties to improve thermal stability and redox performance. The formulation approach involved a solgel process, rapid thermal treatment, and subsequent hydrogen reduction. A central composite design (CCD) was employed to optimize synthesis parameters, including reaction temperatures ranging from 700 to 1000 °C, reaction times from 1–3 h, and a V_2O_5:$Ca(NO_3)_2$ molar ratio of 0.3–1.0. The physicochemical properties of the CaV_2O_6 material were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and Brunauer–Emmett–Teller (BET) surface area analysis. SEM revealed a porous nanosheet morphology, while XRD confirmed the formation of an orthorhombic CaV_2O_6 phase. BET analysis showed an average surface area of 25.340 m^2/g, representing a 40.6% increase compared to a conventional $Ca(OH)_2$ sorbent (18.019 m^2/g). The developed material suggests that the laboratory-scale synthesis protocol is capable of replacing costly dry flue gas desulfurization reagents with those derived from sustainable precursors.

2.91. Systematic Literature Review of Applications of Operation Research in Green Logistics

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Since the signing of the Paris Agreement in 2016, there has been a growing emphasis on achieving sustainability across various sectors. One of these sectors is logistics. In order for this sector to be sustainable, an area of study called Green Logistics has been established. The aim of this study is to provide a literature analysis that represents the applications of Operation Research in Green Logistics, while also seeking to pinpoint gaps in research concerning these applications and offer insights for future investigations.

Leveraging data from the Web of Science and Scopus databases since 2021, duplicate records are eliminated using R Studio. VOSViewer software is used to analyze bibliometric networks, resulting in findings that include a classification of studies based on their country relationships and prevalent research fields. Moreover, a thorough examination of articles are conducted, categorizing them according to their objective functions and solution methods.

The results are evaluated to identify research gaps and potential future studies. Through Keyword co-occurrence analysis, the top three prevalent research areas are identified. These are Electrical Vehicle, Routing, and Cold Chain Logistic. The solution methodologies frequently involve algorithms, often comprising combinations of two algorithms or improvements to existing ones. This study contributes to advancing knowledge in the field of applications of Operation Research in Green Logistics.

2.92. Toward Copper–Silver Electrochemical Nanosensor for 1,3-Dinitrobenzene

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Nitroaromatic compounds, such as 1,3-dinitrobenzene (DNB), are widely used in the manufacture of dyes, explosives, and pesticides and are frequently detected as persistent pollutants in industrial wastewater. DNB is classified as a toxic and potentially carcinogenic compound; it can be absorbed through inhalation, ingestion, or skin contact and is known to affect the central nervous system. Due to its stability in aqueous media and resistance to biodegradation, DNB poses a serious threat to aquatic ecosystems and human health, emphasizing the need for sensitive and efficient detection methods.

In this study, we report a fast, simple, and low-cost synthesis of a bimetallic CuAg/rGO (copper–silver on reduced graphene oxide) nanocomposite intended for the electrochemical detection of DNB in water samples. Material characterization was performed using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM/EDX) and transmission electron microscopy (TEM), confirming the formation of Cu and Ag nanoparticles homogeneously distributed over the rGO surface and embedded within its layered structure.

The electrochemical activity of a glassy carbon electrode modified with CuAg/rGO was examined by CV. The modified electrode exhibited a distinct reduction peak for DNB at ~ −0.6 V vs. a saturated calomel electrode (SCE). The limit of detection (LOD) was determined to be 2.21 μM within a linear range of 0–50 μM.

These results demonstrate that the CuAg/rGO-modified electrode provides a promising low cost and efficient electrochemical sensing platform for the rapid detection of nitroaromatic pollutants, with potential application in routine environmental monitoring.

2.93. Tailored Graphitic Carbon Nitride–Biochar Composites for Enhanced Photodegradation of Recalcitrant Pharmaceuticals

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Recent environmental assessments have highlighted the urgent need for efficient and sustainable technologies capable of degrading recalcitrant pharmaceutical pollutants in freshwater systems. Among photocatalytic materials, graphitic carbon nitride (g-C_3N_4) has garnered attention due to its visible light activity, chemical stability, and tunable properties. However, its performance is strongly influenced by the precursor material and synergistic modifications. This study explores the efficacy of g-C_3N_4 synthesized from melamine, urea, and thiourea—alongside biochar—as a composite system for the photodegradation of selected persistent pharmaceuticals.

The different sources of g-C_3N_4 were calcined at 550 °C for two hours to obtain a slightly yellowish form of g-C_3N_4, which was then tested on methyl orange dye. Among the sources, urea demonstrated the highest degradability at 60.25%, followed by thiourea at 32.05% and melamine at 7.59%. To enhance the degradation efficiency, urea was blended with melamine and subsequently with thiourea, resulting in improved degradation attributed to the presence of urea. Further optimization involved blending g-C_3N_4 from these

sources with biochar, enhancing both the adsorption capability and photodegradation activity, with urea maintaining a degradation rate of 59.7%. These preliminary investigations led to testing the urea-derived g-C_3N_4 with biochar on the recalcitrant pharmaceuticals, yielding degradation efficiencies of 92.59%, 84.44%, 68.11%, and 61.11% for tetracycline, cefixime, ciprofloxacin, and carbamazepine, respectively. These results indicate that the strategic enhancement of g-C_3N_4 with biochar offers promising potential for advanced water treatment applications targeting pharmaceutical contaminants.

2.94. Techno-Economic and Energy Efficiency Assessment of Scrap Tyre Pyrolysis in Nigeria: A Comparative Analysis of Standalone and Power-Integrated Systems

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The growing accumulation of scrap tyres in Nigeria poses significant environmental and public health risks due to improper disposal methods such as open burning and illegal dumping. In response to this challenge, pyrolysis has emerged as a sustainable waste management and resource recovery technique capable of converting scrap tyres into valuable products such as pyro-diesel, char, and steel wire. However, the economic viability and energy performance of pyrolysis systems remain largely unexplored in the Nigerian context. This study addresses this gap by evaluating the techno-economic feasibility and energy efficiency of scrap tyre valorization via pyrolysis under two configurations: (i) a standalone pyrolysis plant (Scenario 2) and (ii) a pyrolysis plant integrated with power generation (Scenario 1). Process simulations were carried out using Aspen PLUS V12, while cost estimations were conducted with the Aspen Process Economic Analyzer. Both configurations were assessed for a processing capacity of 20 tons per hour. The process yields included pyro-diesel (39.13%), char (35.62%), steel wire (15.04%), pyrolytic gas (7.90%), and heavy oil (2.30%). Energy analysis showed that Scenario 2 attained a higher energy efficiency of 79.72%, compared to 74.76% in Scenario 1. Nonetheless, Scenario 1 demonstrated superior economic performance, with a Net Present Value (NPV) of USD 28.65 million (NGN 42.97 billion) and an Internal Rate of Return (IRR) of 34.48%, despite its higher capital investment. These findings highlight a critical trade-off between energy efficiency and profitability. While standalone pyrolysis systems are more energy efficient, integrating power generation significantly enhances financial returns—making it a more attractive model for large-scale application in Nigeria's waste-to-energy landscape.

2.95. Tensile and Flexural Performance of Glass Fiber Epoxy Composites with Lignocellulose Tea Waste Filler: An Experimental Approach

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This study investigated the mechanical performance of glass fiber-reinforced epoxy composites incorporating varying percentages of tea waste filler, a globally abundant lignocellulosic by-product, with the objective of evaluating its influence on their tensile and flexural properties and providing insights into its potential as a sustainable filler. Unfilled composites (Category A) exhibited the highest tensile strength (298.69 MPa) and elastic modulus (4928.67 MPa), attributed to optimal fiber-matrix bonding. However, compos-

ites with 2% tea filler (Category D) demonstrated the highest toughness (12,468.91 kJ/m^3) and energy absorption in tensile tests, highlighting the filler's ability to dissipate energy during deformation. Similar trends were observed in flexural tests; while unfilled composites achieved the highest flexural strength (349.43 MPa), the addition of 0.5% filler (Category B) enhanced stiffness (elastic modulus: 19,230.5 MPa). Higher filler contents generally reduced strength due to particle agglomeration and weak interfacial bonding, but significantly improved toughness and energy absorption under flexural loading. The study underscores the potential of tea waste as a sustainable filler to enhance toughness and energy absorption in polymer composites, making them suitable for applications in industries requiring lightweight and durable materials. Future research should explore advanced filler modification techniques, such as silane treatment, to optimize strength and stiffness by improving filler dispersion and matrix bonding, and assess performance under long-term environmental conditions.

2.96. The Adventure of Egg Waste Becoming a Biosorbent: Egg Shell and Membrane

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Egg waste, one of the most important nutrients for humans, is divided into two groups: egg shells and membranes. These biomass wastes, which are directly disposed of in landfills, have high potential for secondary environmental pollution. In particular, the presence of microorganisms on their surface can affect environmental conditions and environmental health. Residual liquids on the shells can increase foul odors and the growth of flies and insects. Egg shells and membranes, which are active waste components, need to be converted into value-added products in line with the UN Sustainable Development Goals (such as SDG-6 and SDG-12). Therefore, such biomass wastes should be recycled, reused, or converted into products. Egg waste, with its high biosorbent potential, has gained popularity among scientists worldwide for removing various contaminants that cause water pollution (such as dyes, heavy metals, pesticides, drug residues, endocrine disruptors, etc.). Egg waste is particularly valuable due to its easy availability, low cost, biodegradability, and environmental friendliness. In this context, egg shells and membranes were subjected to separate processes. This review article examines the stages (breaking, grinding, sieving, separation, washing, etc.) of egg waste before it begins its journey as a biosorbent, with detailed evaluations of the applied techniques, physicochemical properties, and mechanisms.

2.97. The Application of an Adaptive Neuro-Fuzzy Inference System for the Removal of Cadmium (II) from Acid Mine Drainage onto Modified Cellulose Nanocrystals

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This research uses a modified cellulose nanocrystal composite, a green and biodegradable adsorbent, to remove cobalt (II) using a column study. Fourier transform infrared spectroscopy, scanning electron microscopy, and thermogravimetric analysis were used to characterise the adsorbent. The fixed-bed column was used to remove cadmium (II) at room temperature with process factors, such as pH (4–8), bed height (3–9 cm), flow rate (3–7 mL/min), and concentration (10–20 mg/L). According to the findings, the cobalt

(II) breakthrough occurred quicker for a lower bed height, greater flow rate, and higher cadmium(II) concentration. The Yoon–Nelson model is the most appropriate kinetic model. Deep learning models, such as the adaptive neuro-fuzzy inference model with two algorithms (Backpropagation and Least Squares Estimation), were effectively used to model the effectiveness of cadmium (II) removal in aqueous solution using modified cellulose nanocrystals. To compare the model's predicted results with experimental data, statistical approaches were used, including Marquardt's percentage standard deviation (MPSD), the coefficient of determination (R^2), and Mean Square Error (MSE). The ANFIS model used to predict cadmium (II) adsorption using modified cellulose nanocrystals had a strong correlation value of 0.997 for the Least Squares Estimation (LSE) and 0.999 for the Gradient Descent (Backpropagation), indicating how effectively the trained model predicted the cadmium(II) adsorption process.

2.98. The Potential of Synthetic Fuels from CO_2 and H_2 as a Sustainable Aviation Fuel in Decarbonizing the Aviation Sector

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The aviation industry is currently confronted with unprecedented challenges in mitigating its environmental footprint and attaining carbon neutrality. This review paper offers a succinct summary of the present obstacles impeding the attempts to reduce carbon emissions in the aviation industry. The text explores the constraints linked to conventional aviation fuels and emphasizes the pressing requirement for sustainable alternatives to fulfill strict emission reduction objectives. The subsequent emphasis is placed on the auspicious prospects of synthetic fuels produced from carbon dioxide (CO_2) and hydrogen (H_2) as a feasible means to reduce carbon emissions in aviation. An innovative strategy involves synthesizing fuels by capturing CO_2 from industrial processes and obtaining H_2 from renewable sources. The article examines the fundamental procedures utilized in the production of synthetic aviation fuels, including electrochemical and thermochemical techniques. In addition, the analysis explores the environmental advantages of synthetic fuels, highlighting their capacity to substantially diminish greenhouse gas emissions and other contaminants. These fuels exhibit both sustainability and versatility, rendering them a highly viable contender for fuelling future aviation fleets. To summarize, this analysis emphasizes the significant capacity of synthetic fuels produced from carbon dioxide (CO_2) and hydrogen (H_2) to function as environmentally friendly aircraft fuels. Examining these possibilities is essential to accomplish the lofty decarbonization objectives established for the aviation sector. This article seeks to provide a thorough understanding that can help to further ongoing research and initiatives aimed at transitioning the aviation sector towards a more sustainable and environmentally friendly future.

2.99. Toward Circular Energy: Recycling End-of-Life Solar Panels and Lithium-Ion Batteries for the Development of Lithium–Silicon Batteries

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The growing deployment of renewable energy systems has raised concerns about the end-of-life management of their components, particularly photovoltaic (PV) panels and lithium-ion batteries. These two waste streams contain valuable materials such as high-purity silicon and lithium, which are critical for energy storage technologies. This study explores a circular approach by recovering silicon from used solar cells and lithium from

spent batteries to fabricate lithium–silicon (Li–Si) batteries, known for their high theoretical capacity and potential to replace conventional graphite-based lithium-ion batteries.

The methodology involves the extraction and purification of silicon from photovoltaic cells through a multi-step process, including chemical etching, thermal treatment, and acid leaching. Simultaneously, lithium is recovered from lithium-ion battery cathodes using hydrometallurgical techniques. The purified silicon is then used as an anode material in a prototype lithium–silicon battery. Characterization techniques such as SEM, XRD, and FTIR are employed to analyze the morphology and purity of the recovered silicon.

Preliminary results show the promising purity levels and structural integrity of the extracted silicon, which meets the basic requirements for battery-grade materials. The study demonstrates the feasibility of transforming waste into high-value components while addressing environmental concerns and supply chain risks.

This project contributes to the development of sustainable, closed-loop energy systems by integrating waste management and battery innovation, supporting both circular economy principles and climate change mitigation strategies.

2.100. Unaccounted Greenhouse Gas Emissions in Agriculture: Detection Challenges and Mitigation Strategies

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Achieving climate change mitigation requires precise assessment of agricultural greenhouse gas (GHG) emissions. Although animal husbandry, soil management, and manure systems primarily address emissions generated directly on farms, hidden or unaccounted emissions remain largely unregulated. Agricultural and rural operations produce significant carbon emissions through indirect activities beyond farm boundaries. This review investigates major sources of greenhouse gas emissions linked to agricultural activities. Agricultural input production and transportation emissions, post-harvest storage and distribution losses, rural development infrastructure emissions, degraded land microbiological activity, and poorly managed or abandoned facilities fall under this category This study examines scientific and administrative challenges to evaluating these emissions. The major challenges include inadequate monitoring systems, unclear accountability, and dispersed rural emission sources. New technological tools, such as satellite-based carbon tracking, remote sensing of soil carbon changes, and machine learning techniques for emission detection will improve monitoring and measurement effectiveness. Mitigation approaches involve implementing full-chain life cycle assessments (LCAs), adapting sustainability frameworks to cover farm and post-farm stages, and developing policy tools that encourage emission management across the agricultural supply chain. Agriculture's environmental impact can be more precisely assessed by including these overlooked sources in greenhouse gas inventories. Adopting holistic approaches helps in crafting effective climate policies, enhancing sustainability certification systems, and empowering farmers, researchers, and policymakers to actively contribute to emission reduction. This study concludes that agricultural and rural greenhouse gas emissions evaluation studies should incorporate cross-disciplinary research methods and scalable technologies.

2.101. Valorisation of Mesosphaerum suaveolens, Calotropis procera, and Chromolaena odorata Invasive Species for Charcoal Production

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Globally, the spread of invasive plant species (IPS) poses substantial ecological and economic problems. Although considered weeds by farmers, such plants are woody-stemmed and lignocellulosic in nature, which, in addition to their abundance and underutilisation, makes them suitable for bioenergy recovery and utilisation. Therefore, the current study seeks to examine the bioenergy potentials of three abundant, problematic, and underutilised IPS, Mesosphaerum suaveolens (MS), Calotropis procera (CP), and Chromolaena odorata (CO), as sustainable raw materials for charcoal production through carbonisation. Additionally, the physico-chemical and energy characteristics of the IPS charcoals are critically examined to present a comprehensive strategy for effective biomass resource management and renewable material/energy production in Nigeria. The carbonisation process was conducted in a muffle furnace at a temperature of 600 °C and with a residence time of 30 min. On completion, the biochars were characterised to examine the impact of the process and plant structure on the biochar mass yield (MY), mass loss (ML), higher heating value (HHV), and energy yield (EY). The results revealed that the IPS charcoals display favourable characteristics. Notably, the MY for MS, CP, and CO ranged from 23.33% to 39.20%, whereas the ML ranged from 60.80% to76.67%. In contrast, the HHV and EY ranged from 25.53 MJ/kg to 27.01 MJ/kg and 6.30 MJ to 10.01 MJ, respectively. The highest ML and HHV were observed from MS, whereas the highest MY and EY were observed for CP. The high values of HHV and EY highlight not only the solid biofuel potential of these abundant, underutilised, and woody IPS but also present a sustainable approach to their ecological management and sustainable energy production. Future studies could critically explore the optimisation of the carbonisation parameters and wider applications of the IPS charcoals.

2.102. Valorization of Construction and Gypsum Waste in Sustainable Portland Cement and Concrete Production

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This study investigates the potential of waste gypsum (WG) as a sustainable substitute for natural gypsum (NG) in the production of ordinary Portland cement (OPC). The WG used was collected from construction site molds and originated from the hydration of Tunisian plaster. Cement samples were prepared by grinding clinker with 3 to 5 wt% of either WG or NG using a laboratory planetary ball mill (Powteq MG 200), producing waste gypsum cement (CMWG) and natural gypsum cement (CMNG), respectively.

To evaluate the suitability of WG, both gypsum types were characterized using X-ray diffraction (XRD), X-ray fluorescence (XRF), and differential scanning calorime-

try/thermogravimetric analysis (DSC/TG). XRD results showed that NG consisted mainly of gypsum dihydrate, while WG contained a mixture of dihydrate and hemihydrate phases. Thermal analysis further confirmed a significantly higher hemihydrate content in WG. These differences could influence cement hydration and setting behavior.

Despite the mineralogical differences, mechanical testing revealed that the flexural and compressive strengths of CMWG were comparable to those of CMNG at all tested ages. This indicates that replacing natural gypsum with waste gypsum does not adversely affect the mechanical performance of the resulting cement.

Overall, the results demonstrate that WG, a construction waste byproduct, can be effectively utilized as a setting regulator in OPC. This substitution contributes to resource conservation and waste valorization without compromising the cement's structural integrity, making it a promising step toward more sustainable construction materials.

2.103. Water Re-Use from Tailings on the Flotation Performance of a Cu-Ni-PGM Ore

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Recycling of process water recovered from tailings dewatering unit operations in mineral processing has become a topical issue owing to the chemistry of recycled water being different from fresh water and how this difference may affect grinding chemistry in the mill, flotation chemistry, and the potential impact on flotation performance. This study examines the impact of recycled water addition to the mill on the flotation performance of a low-grade Cu-Ni-PGM ore over three successive cycles. Synthetic plant water of known ionic strength and composition was used as the baseline. Results showed that while water recovery and froth stability increased with recirculated water, the relationship with solids recovery was not linear suggesting reduced entrainment and a decoupling of froth stability from mineral recovery. Moreover, Cu recoveries showed slight improvement with recycling, while Ni recoveries showed a slight decrease. Significant variation in the accumulation of Ca^{2+}, Mg^{2+}, Cl^{-}, and $SO_4{}^{2-}$ was observed between recirculation strategies, affecting the electrical conductivity. The findings of this study highlight the importance of understanding water chemistry changes within closed-loop systems and its intersection with grinding and flotation processes. Insights from this study can inform water management strategies and reagent schemes that support both metallurgical performance and environmental compliance in PGM concentrators.

2.104. Zero-Energy Cooling for Agricultural Applications Using PVDF-NP-Based Radiative Coatings

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Passive Daytime Radiative Cooling (PDRC) represents a promising zero-energy strategy for thermal regulation by reflecting solar radiation while emitting heat through the atmospheric window (8–13 μm). In this study, PVDF-based PDRC coatings embedded with MgO and ZrO_2 nanoparticles were developed, characterized, and applied for sustainable cooling in agro-based systems. Nanocomposite coatings were prepared using polyvinylidene fluoride (PVDF) as the polymer matrix, incorporating MgO and ZrO_2 nanoparticles individually. Optical characterization showed that ZrO_2-PVDF achieved the highest solar reflectance of 0.96 with only 0.02 absorbance and 0.02 transmittance, while MgO-PVDF exhibited 0.94 reflectance, 0.02 absorbance, and 0.04 transmittance, indicating a high solar rejection and radiative cooling capability.

To evaluate practical cooling performance, coatings were applied on 5 × 5 cm metal and PET strips and exposed to ambient conditions. The MgO-PVDF-coated strip achieved

surface temperatures as low as 28.7 °C at 16:00 h, compared to at 38.2 °C ambient temperature and up to 52.9 °C for black-coated controls. ZrO_2-PVDF also showed significant sub-ambient performance. For application-level validation, a transparent PET box was coated externally with the PDRC films. Under peak sunlight (10:00–16:00 h), the coated PET box consistently maintained internal temperatures 8–11 °C lower than the uncoated box, demonstrating the material's effectiveness in real agro-climatic environments. This study establishes PVDF-based MgO/ZrO_2 nanocomposite coatings as scalable, passive, and power-free cooling solutions, suitable for post-harvest storage, packaging, and field-level applications in agriculture to reduce thermal stress and spoilage.

3. Chemical Processes and Systems

3.1. A Computational Study for Structural and Functional Elucidation of an Uncharacterized TrcS Protein of Mycobacterium tuberculosis Involved in Autophosphorylation

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TB is caused by an infection of MTB, the foremost cause of mortality attributable to a single infectious agent, resulting in numerous fatalities globally. The pathogen often resides in the human body in a dormant state. Because of how common tuberculosis is, scientists need to find new ways to treat it and make anti-tuberculosis vaccines that can handle multidrug resistance and latent TB infections. This study aims to examine the MTB protein sequence, gaining knowledge about its physicochemical properties, structure-based functional analyses, domain anticipation for specific functional predictions, 2D and 3D structures, and the PPI network. The physicochemical parameters indicated that the protein contains a greater number of negatively charged residues compared to positively charged residues in its sequence. The instability index and aliphatic index indicate that this protein is stable and has suitable thermostability. Documentation also confirms the hydrophobic nature of this protein. The protein has a sensor histidine kinase domain that helps phosphorylate a histidine residue and move its phosphate group to HssR. Consequently, this protein can function as an enzyme, engaging in interactions with ATP and protein L-histidine to produce ADP and protein N-phospho-L-histidine. Gene ontology analyses have revealed the protein interactions in cellular, molecular, and biological processes. The PPI network established an interaction network between the selected protein and 10 other proteins. The secondary structural assessment documented that the alpha helix was the most dominant structural element, followed by random coils and extended strands. Moreover, three different programs, namely AlphaFold, I-TASSER, and SWISS-MODEL, modeled the 3D structure of the protein. After studying different structures, the structural assessment study showed that the one predicted by the SWISS-MODEL program was the best one, taking into account the values for the most desired and extra-allowed areas in the plot statistics results.

3.2. A New Extraction System Based on the TBPS/Thymol Hydrophobic Deep Eutectic Solvent

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Today, the development of new generation extraction systems is critically important for the environmentally friendly and efficient recycling of spent Li-ion batteries. Traditional organic solvents are toxic, volatile, and flammable. Hydrophobic deep eutectic solvents

(HDESs) offer a green alternative: they have low volatility, incombustibility, efficiency, and can be obtained from their available raw materials. A large number of eutectic solvents (e.g., based on TOPO, D2EHPA, etc.) have already been studied in the literature and have proven themselves to be promising extraction systems. Their key advantage is the ability to fine-tune the composition for the selective and highly efficient extraction of valuable metals (Li, Co, Ni, Mn, etc.).

The purpose of this work is to develop a hydrophobic deep eutectic solvent based on triisobutylphosphine sulfide (TBPS) and thymol and to study its extraction properties.

The HES was prepared from the hydrogen bond acceptor (TBPS) and donor (thymol) at a molar ratio of 1:1. All extraction experiments were carried out at a temperature of 25 °C and an atmospheric pressure of ~100 kPa in graduated centrifuge tubes with a thermostatically controlled shaker.

The phase equilibrium of the "solid–liquid" system was investigated, and a detailed characterization was conducted. The viscosity of the proposed eutectic solvent is below 30 mPa·s, indicating their technological suitability. The hydrophobicity and chemical stability of the deep eutectic solvent were also examined. An extraction method was developed for the recovery of major metal ions present in the active material of spent LFP batteries (Li, Cu, Al, and Fe). It was found that it is possible to selectively isolate Cu(II) and Fe(III) from 2 to 5 M HCl with high separation factors of 18 and 350, respectively.

Thus, the prospects of using TBPS/thymol HDES for metal ion separation contained in the active materials of spent LFP batteries are shown.

3.3. A Water Model Study on the Floating of Inclusions into the Slag Layer Under a Horizontal Paralleling Flow Condition

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A water model experiment was used to investigate the migration behavior of non-metallic inclusions at the steel–slag interface in the steelmaking process. Based on the two basic principles of static similarity and dynamic viscosity similarity, an experimental model was constructed with alumina and polypropylene particles representing inclusions, water as the simulation fluid of liquid steel, and silicone oil as the simulation fluid of steel slag. On the basis of this model, a pump with adjustable power was added to simulate the paralleling flowing liquid steel. By adjusting the viscosity of silicone oil, particle material, diameter and water flow speed, the movement mechanism of particles floating into the water–oil interface was systematically observed and recorded, and the mechanism of different factors affecting the migration behavior of inclusions was analyzed. It is found that the particles will encounter the deformation resistance of the interface and be bounced downward when they reach the water–oil interface, and then float up for a second time and may successfully cross the water–oil interface. In addition, this study also found that the particle type, size and interface wettability are key factors affecting particle movement at the interface. Due to their high wettability, polypropylene particles show larger dimensionless displacement than Al_2O_3 particles under the same oil layer conditions. At the same time, the increase in particle size helps them to cross the water–oil interface, and the increase in oil layer viscosity increases the resistance of particles to cross the interface. In addition, it was found that the change in water velocity in the dynamic water model also has an effect on the motion of particles, and the increase in flow velocity helps to reduce the difficulty of particles passing through the water–oil interface.

3.4. Advances in MOF Fabrication Techniques: Tuning Material Properties for Specific Applications

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Metal–organic frameworks (MOFs), a class of porous crystalline materials, consist of metal ions or clusters coordinated to organic linkers. The metal center acts as a connection point where the organic ligands form a bridge through coordination, giving rise to one-dimensional, two-dimensional, or three-dimensional networks. The unique features of MOFs such as their exceptionally high surface area, chemical versatility and tunable porosity make them highly suitable for several applications, including gas storage, drug delivery, catalysis, and sensing. The fabrication technique plays an important role in modulating the functional and structural characteristics of MOFs, such as crystallinity, porosity, particle size, morphology, defect density, and adsorption behavior. Various synthesis techniques, including solvothermal, hydrothermal, microwave-assisted, mechanochemical, electrochemical, and sonochemical methods, have been used for the fabrication of MOFs. The selection and optimization of synthesis techniques significantly influence the fundamental framework structure, the existence of defects, the available active sites and the effectiveness of MOFs in special applications. This study focuses on advances in MOF fabrication techniques and examines their role in tuning the key properties of MOFs for targeted applications. Recent studies were collected and comparatively assessed to identify the correlation between fabrication conditions and the resulting physicochemical properties of MOFs. The insights of this work may guide researchers in selecting or designing appropriate fabrication strategies for the application-specific development of MOFs.

3.5. Biofabrication of ZnO and MgO Nanoparticles Using Dracaena trifasciata-Derived Reducing Agents and Their Antimicrobial Activity Against Pathogens

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Various plant-mediated nanoparticles have been used as drugs due to their antimicrobial activity because they are active against various pathogens like bacteria, fungi, etc. ZnO and MgO are emerging as promising antimicrobial agents. Biofabricated nanoparticles were synthesized with *Dracaena trifasciata*, characterized using a field emission scanning electron microscopic (FE-SEM) analysis depicting the spherical shape of the NPs, and an energy-dispersive X-ray (EDAX) analysis confirmed the presence of oxygen and zinc in the synthesized NPs. XRD (X-ray diffraction) patterns were recorded to measure the size and phase of the NPs. The MgO nanoparticles have particle size distributions lower than 11.5 nm. The agar well diffusion method was used to assess the antibacterial activity of samples SRNP-1, SRNP-2, and SRNP-3 against Gram-positive (*Bacillus subtilis*) and Gram-negative (*Escherichia coli*) bacterial strains. Among the isolates, SRNP-1 showed the highest activity against Escherichia coli, with an inhibition zone of 30.33 $\pm$ 0.58 mm at 100 μg/mL, comparable to the standard antibiotic gentamycin (30.67 $\pm$ 0.58 mm). SRNP-2 and SRNP-3 also displayed activity, with inhibition zones of 26.67 $\pm$ 2.31 mm and 24.33 $\pm$ 0.58 mm, respectively, at 100 μg/mL. Nanoparticles of ZNO and MgO can significantly improve

food packaging materials by enhancing their **mechanical strength**, **barrier properties**, and **antimicrobial activity**, ultimately **extending shelf life** and improving **food safety**.

3.6. Chemical Equilibrium and Kinetics in the Autocatalytic Reaction System 2,2,2-Trifluoroacetic Acid–Propan-1-ol–Water–Propyl 2,2,2-Trifluoroacetate

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The esterification reaction of alcohols and acids is a fundamental method for synthesizing esters. Such reactions can occur via a nucleophilic substitution mechanism, facilitated by the protonation of the oxygen atom in the carbonyl group of the acid. The scientific literature extensively addresses systems in which one of the reactants is a weak acid, necessitating the use of an external catalyst for the reaction to proceed. In contrast, systems that involve a strong acid as one of the reactants exhibit autocatalytic behavior. A notable example is the esterification reaction between an alcohol and trifluoroacetic acid (TFA), which possesses an acidity comparable to that of strong mineral acids. Despite the investigation of such reactions across various systems, experimental data on the chemical equilibrium and kinetics remain limited. Additionally, the theoretical foundations of autocatalytic esterification kinetics and the existing models for such systems are not universally applicable. This study focuses on the chemical equilibrium and kinetics of the esterification reaction between TFA and propan-1-ol (Pol) without the introduction of an external catalyst. Data on the equilibrium constant were obtained within a temperature range from 30 to 70 °C. The results indicate that a reaction system with initial TFA concentrations of up to a 0.3 mole fraction ($x_{TFA}/x_{Pol} \leq 3/7$) falls within the homogeneous area of chemical equilibrium compositions. The temperature dependence of the Van't Hoff equation parameters indicates that the reaction is endothermic within this area. Kinetic data were collected for the homogeneous equilibrium area within a temperature range from 30 to 80 °C. Existing models of autocatalytic esterification do not adequately describe the reaction kinetics, primarily because they treat the reaction rate coefficient as a constant. To address this limitation, the present study proposes a model that accounts for the dependence of the activation energy on the TFA concentration. Such an approach provides an adequate description of the experimental data.

3.7. Cobalt Bromide-Filled Single-Walled Carbon Nanotubes: Structure and Electronic Properties

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The filling of single-walled carbon nanotubes (SWCNTs) is a promising method for controlling the properties of SWCNTs for applications. Filling of SWCNTs with metal halides, metal chalcogenides, metals, and metallocenes is performed. Metal halides are a large group of filling substances with large work functions. Filling of the SWCNTs with metal halides leads to p-doping of the SWCNTs. Metal chalcogenides can lead to p-doping of the SWCNTs, too. Metals with low work functions result in n-doping of the SWCNTs. Filling of the SWCNTs with metallocenes with further annealing leads to variations in the doping types of the SWCNTs. The electronic properties of the filled SWCNTs are important for nanoelectronics, electrochemical energy storage, and biomedical applications. SWCNTs filled with various substances with tailored electronic properties can be applied in those fields. The electronic properties of the filled SWCNTs are influenced by the structure of the filled material. The structure of the filled materials defines their band

structure. In SWCNTs with different diameters, various structures of the filled materials are obtained. This influences the electronic properties of the filled SWCNTs. Here, the structure and electronic properties of cobalt bromide-filled SWCNTs are investigated. Using high-resolution transmission electron microscopy and Raman spectroscopy, we reveal the properties of the filled SWCNTs. Novel structures of cobalt bromide-filled SWCNTs with large p-doping are observed. The obtained data are important for various uses of the filled SWCNTs.

3.8. Comparative Evaluation of Ethanol, Methanol, and Aqueous Extracts of Dandelion (Taraxacum officinale) Root for Nutraceutical Applications

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Introduction: Dandelion (*Taraxacum officinale*) root is source of bioactive compounds, including phenolic acids, flavonoids, polysaccharides, and fatty acids, which contribute to its traditional applications in herbal medicine, functional foods, and nutraceuticals. The extraction efficiency of these phytochemicals substantially depends on the solvent used. This study aims to evaluate the chemical, physicochemical, antioxidant, and fatty acid profiles of dandelion root extracts using ethanol, methanol, and aqueous as solvents.

Methodology: Dried dandelion root powder (20 g) was subjected to Soxhlet extraction using 200 mL of ethanol, methanol, and distilled water(w/v). The resulting extracts were analyzed for physicochemical properties including moisture content, pH, and titratable acidity using standard AOAC methods. Functional groups were identified using FTIR. Bioactive compounds were identified using Gas Chromatography–Mass Spectrometry (GC-MS), while fatty acid composition was determined using Gas Chromatography with Flame Ionization Detection (GC-FID). Antioxidant activity was evaluated through DPPH radical scavenging activity and total phenolic content.

Results: Ethanolic and methanolic extracts exhibited higher yields of phenolic compounds (16.43 mg GAE/mL and 18.11 mg GAE/mL, respectively) compared to the aqueous extract, whereas aqueous extracts were notably rich in polysaccharides and demonstrated good antioxidant properties, reflected by higher 73% DPPH activity. FTIR spectra confirmed the presence of hydroxyl, carboxyl, and alkene functional groups across all extracts. GC-MS analysis revealed a diverse range of bioactive compounds, including essential fatty acids (17.7 min), esters (31.08 min, 47.1 min), furans (16.6 min), amino acid derivatives (41.3 min, 15.08 min) and polysaccharides (55.3 min). The ethanolic extract showed the higher polyunsaturated fatty acid (PUFA) content, particularly linoleic (15.17 g/100 mL) and linolenic acids (4.15 g/100 mL).

Conclusions: The type of solvent significantly impacts the extracted bioactive compounds from dandelion roots. Ethanol extract proved effective for extracting phenolics and PUFAs, indicating suitability for nutraceutical applications. Aqueous extraction is preferable when targeting polysaccharides with high DPPH activity. These findings support solvent-specific extraction strategies for developing targeted nutraceuticals.

3.9. Computational Studies of Thiosemicarbazone-Based Metal Complexes and Their Biological Applications

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Thiosemicarbazones are known for their versatile coordination behavior and wide-ranging applications in the fields of materials science, catalysis, and medicinal chemistry. Metal complexes of thiosemicarbazones are extensively studied because of their remarkable properties and diverse applications in various scientific disciplines. Several investigations have reported on the biological potential of transition metal complexes of TSCs, including antifungal, antiviral, antibacterial, and anticancer activities. Studies on heterocyclic TSC complexes have become more prevalent. In addition, the structural, electronic, and reactive properties of these complexes are explored through computational studies using molecular docking and density functional theory (DFT). Such investigations not only support the interpretation of experimental results but also influence synthetic design by predicting the structural behavior of the complexes. Moreover, these computational techniques enable researchers to examine electronic structures and spectroscopic characteristics, which are crucial for establishing Structure–Activity Relationships (SARs) and understanding reactivity patterns. The gap between experimental research and theoretical understanding is bridged by computational studies, enabling the behavior of metal complexes in various biological and chemical systems to be predicted and optimized. The design and development of more effective compounds for various applications is made easier by this approach. In this study, we explore computational studies of thiosemicarbazone metal complexes along with their biological activities.

3.10. Convolutional Neural Networks for Polymer Identification Through Infrared Spectra

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The growing volume of plastic waste has intensified the demand for efficient and automated methods to identify and sort polymeric materials, especially in recycling facilities where speed and accuracy are essential. Infrared spectroscopy is widely used for polymer identification due to its sensitivity to molecular vibrations. However, interpreting spectral data can be challenging when polymers have similar chemical structures, such as polypropylene and polyethylene. The objective of this work is to develop a methodology that employs the Gramian Angular Summation Field as a preprocessing step for a Convolutional Neural Network to distinguish polypropylene and polyethylene based on their infrared spectra. The dataset comprises 948 spectra of various post-consumer plastic materials. After converting the one-dimensional spectra into two-dimensional images, the neural network architecture includes a single convolutional layer, a dense layer, and a final output layer for multiclass classification, distinguishing between polyethylene, polypropylene, and other polymers. The model achieves average precision, recall, and accuracy of approximately 97% on the validation set and around 91% on the test set, indicating good generalization performance. By successfully integrating infrared spectroscopy with time-

series-to-image conversion, this work shows that high-performance polymer classification is achievable with lightweight neural networks, reinforcing the potential of this approach for efficient and automated plastic sorting in future recycling systems.

3.11. DWSim-Based Process Simulation of Flash Distillation for Acetone–Chloroform Azeotrope: Influence of Temperature and Entrainers on Separation Efficiency

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Azeotropic mixtures such as acetone–chloroform present considerable challenges to conventional separation methods due to their constant boiling behavior, which limits the effectiveness of ordinary distillation techniques. Overcoming these limitations often requires the use of entrainers to break the azeotrope and enhance component separation. However, understanding the interplay between temperature, entrainer type, and the quantity introduced remains a key challenge in optimizing separation performance. This study investigates the flash distillation of an acetone–chloroform binary azeotrope using process modeling and simulation to evaluate how operating temperature and entrainer concentration (introduced via flow rate) affect the separation efficiency. Two entrainers were assessed—water and a secondary organic compound—with simulations conducted across varying temperatures and entrainer dosages. The results reveal that temperature changes have a greater impact on separation efficiency when an entrainer is present, with higher entrainer concentrations significantly enhancing phase separation and making the system less sensitive to temperature fluctuations. Among the entrainers examined, water consistently outperformed the alternative by improving the ease and extent of separation. These findings highlight the critical role of entrainer selection and dosing strategy in azeotropic separation via flash distillation. The insights gained offer a practical basis for improving process design, reducing energy demand, and enhancing product purity in both industrial and research applications. The modeling approach also provides a cost-effective tool for screening and optimizing separation strategies for similar complex mixtures.

3.12. Development of a Green Method for the Synthesis of Xanthene-1,8-Dione Derivatives from Dimedone and Aldehydes

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Xanthene-1,8-dione derivatives are of significant interest in pharmacology and materials chemistry due to their biological and optical properties. However, their traditional synthesis often involves toxic catalysts or environmentally harmful solvents. We propose a novel eco-friendly approach for synthesizing these compounds using green reaction conditions, avoiding hazardous organic solvents and minimizing unwanted byproducts.

The synthesis is carried out via condensation between dimedone and various aldehydes in the presence of linear alkylbenzene sulfonic acid (LABSA) as a biodegradable and cost-effective phase-transfer catalyst and under alternative activation methods such as ultrasound irradiation. The reaction is optimized to maximize yield while reducing environmental impact. LABSA, functioning both as a Brønsted acid and surfactant, is proposed to facilitate a multicomponent cascade process involving Knoevenagel condensation, Michael addition, and intramolecular cyclization.

Xanthene-1,8-dione derivatives are obtained in high yields (88–90%) with excellent purity. The method offers significant advantages, including reduced reaction time, atom economy, and easy purification. The products are characterized by spectroscopy (NMR, IR,

MS) and chromatographic analysis. In IR strong carbonyl stretching bands observed near ~1623–1634 cm^{-1} are characteristic of two conjugated carbonyl groups at positions 1 and 8 of the xanthene core.

This green strategy provides a sustainable alternative to conventional protocols, aligning with the principles of green chemistry. It opens new possibilities for the eco-friendly synthesis of heterocycles valuable in pharmaceuticals and fine chemistry.

3.13. Discrete Modeling of Pore Evolution in Limestone Particle Calcination and Carbonation

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Building on our previous work on discrete modeling of pore evolution in a single limestone particle during calcination, this study extends the model to include both pore expansion due to CO_2 production (forward reaction) and pore shrinkage resulting from CO_2 accumulation in the pore walls (reverse reaction). These competing phenomena are modeled through local thermal energy balances, coupled with the transport of gas species. The local reaction rates for calcination and carbonation are determined by kinetic parameters, active surface area, and gas species partial pressures. The results capture the dynamic evolution of solid grains and pore structures over time, accurately resolving local conversion profiles and pore size distributions. By incorporating both expansion and shrinkage effects, the model provides a realistic representation of structural transformations during thermochemical cycling. Furthermore, the framework enables simulation of the full Ca-looping process by using the calcined product (CaO) as a reactive carrier for CO_2 absorption. The model reveals local pore-scale structural evolution during carbonation, including the formation of occluded or closed pore regions. This mechanistic insight highlights the feedback between pore morphology and reactivity, offering critical guidance for the design of efficient carbon capture and looping systems. These findings are essential for developing accurate single-particle continuum models and contribute significantly to understanding transport in reactive porous media.

3.14. Efficient Phenol Degradation by a Natural Illite-Based Catalyst via Integrated Advanced Oxidation Processes

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Phenol is a hazardous aromatic compound frequently detected in industrial effluents, posing serious risks to aquatic ecosystems and human health. In this study, a natural illite-based catalyst impregnated with 2% iron (Fe@SCRT) was synthesized and evaluated for phenol degradation via various advanced oxidation processes (AOPs), including Fenton, Sono-Fenton, Photo-Fenton, and their combined forms.

The catalyst was characterized using XRD, FTIR, and SEM-EDX, confirming successful iron incorporation and structural modification. Among the tested processes, the combined Sono-Photo-Fenton system achieved the highest degradation efficiency, exceeding 95% phenol removal within 60 min. Operational parameters such as pH, H_2O_2 concentration, and catalyst dosage were optimized to enhance performance. Statistical analyses, including standard deviation and ANOVA, revealed significant differences among individual and combined processes.

Scavenger studies identified hydroxyl radicals as the primary oxidative species, with contributions from superoxide radicals and metal ions. The catalyst showed good stability across multiple reuse cycles with minimal iron leaching.

Preliminary eco-toxicological tests, including seed germination and fish survival assays, demonstrated a clear reduction in effluent toxicity after treatment, supporting the environmental viability of the approach.

This study introduces a novel integration of multiple AOPs using a low-cost, natural clay-based catalyst, with both performance and toxicity assessments. The synergistic effect of the Sono-Photo-Fenton process using Fe@SCRT is reported here for the first time. These findings highlight the potential of Fe@SCRT as a sustainable and efficient catalyst for wastewater treatment applications.

3.15. Electrochemical Synthesis of Ortho- and Para-Hydroxybenzoic Acids Using CO_2: Experimental and Simulation-Based Optimization

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The electrochemical synthesis of ortho- and para-hydroxybenzoic acids (o-HBA and p-HBA) utilizing CO_2 as a carbon source represents a sustainable and energy-efficient alternative to traditional high-temperature synthetic methods, such as the Kolbe–Schmitt reaction. These hydroxybenzoic acid isomers are valuable intermediates in pharmaceuticals, polymers, and cosmetics. This study presents an integrated approach combining experimental electrochemical analysis with process modeling using Aspen Plus to optimize key parameters affecting product yield and selectivity. Laboratory experiments identified the optimal reaction conditions at an applied potential of -1.2 V (vs. Ag/AgCl), 3 atm CO_2 pressure, and 50 °C, yielding 55.6% o-HBA and 38.2% p-HBA. Electrochemical behavior was further supported by simulations incorporating electrolyte thermodynamics (ELECNRTL) and yield-based reaction blocks (RYield), which accurately reflected observed trends. The model also included a recycle loop that improved the effective CO_2 utilization to over 76.8%, demonstrating process efficiency and resource recovery. Despite slight discrepancies between experimental and simulated yields due to modeling simplifications, the framework proved effective for evaluating process scalability. The study underscores the potential of CO_2-based electrochemical methods as green pathways for producing high-value chemicals while contributing to carbon mitigation strategies. This work lays a foundation for future advancements in reactor design, catalyst development, and industrial integration of CO_2 valorization technologies, aligning with global sustainability goals and the circular carbon economy.

3.16. Evaluation of Copper Extraction on Low-Grade Oxide Ores Using Column Heap Leaching

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Heap leaching is an economically viable hydrometallurgical technique extensively employed in the mining industry for extracting valuable metals such as copper from low-grade ore deposits. This method renders a cost-effective solution for processing ore that would otherwise be considered uneconomical for conventional extraction techniques. This study investigates the efficiency of copper recovery from different particle size fractions

of low-grade oxide ores that have undergone crushing stage. Hydrochloric acid was used as a lixiviant in column heap leaching experiments to study the effect of particle size on copper extraction recovery. The experiments were conducted using column leach setups with dimensions of 150 mm in diameter and 2 m in height. Crushed ore samples, ranging in particle size from 25 mm down to 1.8 mm, were divided into 5 kg aliquots and loaded into the columns, with a total mass of approximately 40 kg per test. Leaching was performed over a period of 16 days using an acid concentration of 200 g/L. The results demonstrated promising copper recoveries. One sample achieved a copper extraction rate of 75% within 16 days, with maximum acid consumption reaching 23 kg/ton over 15 days. Another sample yielded a comparable copper recovery of 74% under the same timeframe but required a higher acid consumption rate of 30 kg/ton. Moreover, the consistent linear increase in copper recovery throughout the leaching period suggests minimal interference from pregnant solution robbing impurities in the ore that consumes the lixiviant.

3.17. Extraction of Fe(III) Ions with Hydrophobic Eutectic Solvents Based on Aliphatic Alcohols and Octanoic Acid

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Today, hydrophobic eutectic solvents are promising extractants for metal ions. Their main advantage is the "adjustability" of their physicochemical and extraction properties due to a wide range of compounds suitable for preparation. In this study, eutectic solvents based on octanoic acid and aliphatic alcohols (1-decanol, 1,9-nonanediol, geraniol, linalool) will be investigated for the extraction of Fe(III) ions, which are often present in various mixtures, such as wastewater, leaching solutions of lithium iron phosphate batteries, etc. The octanoic acid/alcohol ratio in eutectic solvents was 1/1. The ratio of aqueous and organic phases during extraction was also 1/1. The Fe(III) distribution coefficient was calculated as the ratio of the equilibrium concentration of Fe(III) ions in the eutectic solvent phase to the equilibrium concentration of Fe(III) ions in the aqueous phase. It was found that with an increase in the pH of the initial solution from 1.4 to 2.4, the Fe(III) distribution coefficient increased. In addition, the extraction efficiency depends on the aliphatic alcohol and increases in the following series: linalool, 1,9-nonanediol, geraniol, 1-decanol. The distribution coefficients at pH 2 were 0.95, 1.36, 1.69, 2.07, respectively. The results indicate that the structure of the aliphatic alcohol affects the extraction capacity of octanoic acid. The reason for this may be multiple hydrogen bonds and Van der Waals interactions between the components, which may hinder the extraction of Fe(III) ions due to steric hindrance. For example, linalool is a tertiary alcohol, which may be the reason for the formation of multiple interactions between the components of the eutectic solvent and, as a result, the reason for the lowest extraction capacity.

3.18. Facilitation of Amine-Bridged Covalent Triazine Framework Synthesis by Microwave Irradiation

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Covalent triazine frameworks (CTFs) are nitrogen-rich porous polymer networks composed of 1,3,5-triazine rings linked by organic moieties via covalent bonds. These materials often exhibit high thermal stability and specific surface areas. Their heteroatom-

rich structure [1] makes them attractive for catalysis and gas adsorption applications. One of the efficient synthetic routes for obtaining CTFs is the nucleophilic substitution between cyanuric chloride (2,4,6-trichloro-1,3,5-triazine) and polyfunctional amines, which forms –NH–bridged triazine networks. These syntheses could be performed under conventional heating methods; however, complete substitution often requires prolonged reaction times.

Microwave irradiation has emerged as a powerful method in such types of reactions due to rapid and uniform energy input, accelerating the substitution and formation of CTFs under mild conditions. For example, the –NH–linked triazine framework was synthesized in just 30 min via microwave heating (400 W) from cyanuric chloride and melamine [2].

According to our results, the reaction between melamine and cyanuric chloride in DMSO for 3 days yielded 31% of –NH–linked CTF, while in microwave conditions. it proceeds for 1 h under 50–200 W, with a double yield of 67%. Moreover, the synthesis of CTF from melamine and pararosaniline under conventional heating did not proceed, but under microwave-assisted heating, we isolated the product with 48% yield.

Thus, microwave-assisted routes significantly reduce reaction times and improve yields. This work highlights how microwave-driven nucleophilic substitution strategies can efficiently produce –NH–bridged CTFs, offering a scalable pathway for these functional porous materials.

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3.19. Functionalized MOFs for Selective Dye Removal: A Mechanistic Study of Cationic and Anionic Adsorption

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Functionalized metal–organic frameworks (MOFs) are increasingly recognized as efficient materials for the selective removal of synthetic dyes from aqueous solutions. To enhance selectivity, MOFs were functionalized with both electron-donating and electron-withdrawing groups, specifically $–NH_2$, –COOH, and $–SO_3H$, thereby adjusting their surface characteristics to favor interactions with oppositely charged dye species. Methylene blue and Congo red were selected as model cationic and anionic dyes, respectively, and adsorption performance was evaluated across a range of pH values and temperatures. Key interaction forces such as electrostatic attraction, hydrogen bonding, π–π stacking, and pore accessibility were considered. Adsorption behavior was analyzed through kinetic and isotherm models, including pseudo-second-order and Langmuir/Freundlich equations, revealing that the functionalized MOFs demonstrated both high dye uptake and fast adsorption rates. This work examines how cationic and anionic dyes interact with chemically modified MOFs, with an emphasis on elucidating their adsorption mechanisms. Characterization techniques including zeta potential, FTIR spectroscopy, UV-Visible spectroscopy and pH-responsive adsorption studies confirmed that adsorption mechanisms were influenced by both the dye charge and the functional groups present on the MOFs. It was observed that amino-functionalized MOFs were more effective in capturing anionic dyes, whereas sulfonated frameworks showed enhanced binding with cationic dyes. These results underscore the role of precise functionalization in tailoring the adsorption properties of MOFs. The mechanistic insights gained from this study can inform the design

of next-generation MOF-based materials aimed at efficient and selective dye removal in wastewater treatment applications.

3.20. Gel Polymer Electrolytes Based on Polyacrylate Copolymer for Energy Storage

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Lithium-ion batteries are the main source of energy for portable devices today and are becoming more deeply embedded in the transport sector every year. However, their energy density approaches a limit of 300 Wh/kg. Overcoming this limitation is possible if pure lithium is used as an anode material. A key obstacle to the widespread adoption of this technology is the problem of dendrite formation, which leads to short circuits, overheating, and explosions.

The formation of dendrites in batteries is caused by the accumulation of charge near the anode. To prevent dendrite formation, it is useful to covalently bond anions to the polymer matrix, which increases the transference number of cations and brings them closer to one.

Copolymers based on ion-conducting acrylates are promising materials due to their simple synthesis, low cost of monomers, and ability to vary the chemical composition. However, current research on these materials is fragmented, leading to gaps in our understanding of how the properties of these gels depend on their composition and structure.

In this study, we aim to conduct research on the relationships between the synthesis conditions, composition, and structure of gel polymer electrolytes based on acrylates, and their performance in lithium metal batteries.

The polymer was obtained through thermal polymerization initiated by benzoyl peroxide. Polymerization was carried out under vacuum to prevent atmospheric water from interfering with the process. The resulting polymer membrane was then flooded with a mixture of ethylene carbonate, propylene carbonate, and $LiPF_6$.

Impedance spectroscopy showed that the ionic conductivity of this particular polymer electrolyte was 0.58 mS/cm, comparable to other promising electrolytes. The lithium transference number was determined using the Bruce–Vincent method. A value of 0.58 for the cation transference number indicated the predominant transport of cations, suggesting a potential solution to the problem of dendrite formation.

3.21. In-Vitro Antioxidant Activity and Quantitative Estimation of Quercetin in Ethyl Acetate Fraction of Acetone Extract of Hardwickia binata

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The present study aimed to evaluate the antioxidant activity and perform high-performance thin-layer chromatography (HPTLC) analysis of the ethyl acetate fraction of the acetone extract of Hardwickia binata Roxb. The ethyl acetate fraction was assessed for in-vitro antioxidant activity using various methods, including the Cupric Reducing Antioxidant Capacity (CUPRAC) assay, 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging assay, hydroxyl free radical scavenging assay, reactive nitrogen oxide scavenging assay, superoxide anion radical scavenging assay, ABTS radical scavenging assay, and Ferric Reducing Antioxidant Power (FRAP) assay. The half-maximal inhibitory concentration (IC_{50}) values were determined for each assay: CUPRAC (4.9 $\pm$ 1.1 µg/mL), DPPH (39.05 $\pm$ 0.09 µg/mL),

hydroxyl free radical scavenging (11.62 ± 0.0931 μg/mL), reactive nitrogen oxide scavenging (435.2 ± 0.01 μg/mL), superoxide anion radical scavenging (16.89 ± 0.06 μg/mL), ABTS radical scavenging (14.9 ± 1.1 μg/mL), and FRAP (2.442 ± 0.12 μg/mL). HPTL Among these, the CUPRAC and FRAP assays exhibited the most significant antioxidant activity C fingerprinting of the ethyl acetate fraction under UV light revealing the presence of seven components with retention factor (Rf) values of 0.012, 0.073, 0.12, 0.18, 0.569, 0.658, and 0.935. The ethyl acetate fraction was further analyzed for quercetin content using HPTLC densitometric analysis with a solvent system comprising toluene: ethyl acetate: methanol: glacial acetic acid (5:4:0.5:0.5, v/v). The analysis was performed on precoated silica gel 60F254 plates, and densitometric detection of quercetin was conducted at 254 nm and 366 nm. The amount of quercetin was quantified by comparing with a standard calibration curve (linear range: 200–600 ng/spot, r^2 = 0.9989). The concentration of quercetin in the ethyl acetate fraction was 43.41 μg/mg of the dry fraction. The results indicate that Hardwickia binata contains natural antioxidants.

3.22. Influence of Acid Hydrolysis Parameters on Monomeric Sugar Production from Chicken Manure

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The utilization of waste biomass, such as chicken manure (CM), for producing valuable products like fermentable sugars has gained increasing research attention. However, limited studies have explored the effect of acid pretreatment on sugar recovery efficiency specifically from CM. This study investigates the production of glucose and xylose from CM using dilute sulfuric acid (H_2SO_4) at concentrations of 0.6, 0.8, and 1.0 M under varying conditions. The results indicate that the highest yields were achieved from decrystallized CM, producing 46.21 mg glucose/g CM and 8.47 mg xylose/g CM under optimal conditions of 0.6 M H_2SO_4 and 100 °C. In contrast, non-decrystallized CM yielded 13.98 mg glucose/g CM and 1.67 mg xylose/g CM under 1.0 M H_2SO_4 and 100 °C. The decrystallization process using concentrated sulfuric acid effectively disrupted the lignin structure and partially hydrolyzed hemicellulose, enhancing cellulose accessibility during subsequent dilute acid hydrolysis. The study also revealed that glucose and xylose yields decreased as the dilute acid concentration increased from 0.6 to 0.8 M and temperature rose from 80 to 100 °C for decrystallized CM. Conversely, for non-decrystallized CM, sugar yields increased with higher acid concentration and temperature. These findings highlight the critical role of pretreatment in improving sugar recovery from CM and suggest that optimizing acid concentration and thermal conditions can enhance the efficiency of biomass conversion. This research contributes to the sustainable valorization of agricultural waste into bio-based products.

3.23. Integrated Process Development and Optimization of Anaerobic Digestion of Septic Sludge for Renewable Biomethane Generation

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Septic tank sludge, rich in organic content, presents a valuable opportunity for renewable energy generation through anaerobic digestion. This study explores its potential for biomethane production by developing and optimizing a bioconversion system. Extensive experimental work began with the physicochemical characterization of the sludge, including proximate and ultimate analyses, which revealed a high heating value (HHV) of 14.324 MJ/kg and favorable elemental composition for energy recovery. Batch anaerobic digestion experiments were conducted under controlled conditions to assess system performance, with pH, volatile fatty acids (VFA), and total ammonia nitrogen (TAN) maintained within optimal ranges to ensure process stability. Simulation and process modeling were carried out using Aspen Plus, and the model was validated against experimental methane yield data, achieving an excellent fit (R^2 = 0.9917). Key operational parameters, including temperature, hydraulic retention time (HRT), and organic loading rate (OLR) were optimized using Response Surface Methodology (RSM). The analysis identified that a hydrolysis temperature of 35 °C, a digestion temperature of 60 °C, HRT of 35 days, and OLR of 37.907 L^1 day^1 produced the highest biomethane output at 99.98%, with up to 96.67% degradation efficiency. These findings confirm that precise control and optimization of digestion conditions can significantly enhance biogas yield from septic tank sludge. The validated model and experimental insights contribute to the development of sustainable waste-to-energy solutions, offering a practical approach to mitigating environmental and public health challenges posed by improper sludge disposal.

3.24. Lead Halides in Single-Walled Carbon Nanotubes

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Single-walled carbon nanotubes (SWCNTs) were filled with various materials. Metal halides are the most popular group of filled materials. Among them are 3d, 4d, and 4f metal halides, such as iron halides [1], cadmium halides [2], and terbium halides [3]. In this work, we filled SWCNTs with novel 6p metal halides, lead chloride, lead bromide, and lead iodide. The novelty of this work is the new incorporated materials, which were filled in SWCNTs with a diameter of 1.4 nm. Indeed, we filled SWCNTs with three materials with various properties, and we investigated the filling and electronic properties of the lead halide-filled SWCNTs. The aim of this work was to analyze the filling ratios, microstructure, chemical composition, and electronic properties of lead halide-filled SWCNTs. The investigation methods were scanning transmission electron microscopy (STEM), Raman spectroscopy, and X-ray photoelectron spectroscopy (XPS). STEM showed the filling of the SWCNTs, and XPS confirmed the chemical composition of the lead halide-filled SWCNTs. Raman spectroscopy at different laser wavelengths between 458 and 647 nm showed variations in the properties of the lead halide-filled SWCNTs. In the radial breathing mode and G-band, the components showed shifts, which indicated doping. The C 1s XPS data confirmed the p-doping of the filled SWCNTs. The obtained data are necessary for nanoelectronic applications of the filled SWCNTs.

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3.25. Modeling and Performance Analysis of a Modified Gas-Liquid Separator for Contaminant Removal from Natural Gas

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The purification of raw natural gas is critical for removing contaminants such as water vapor, gas condensates, and mechanical impurities that can impair downstream equipment and reduce gas quality. In this study, we present a comprehensive modeling, simulation, and experimental analysis of a modified three-phase gas-liquid separator tailored for high-load natural gas streams. The separator design incorporates thirty suspended baffles and a novel anti-foam mesh, which were geometrically optimized using experimental fluid dynamics principles. Aspen Plus simulations were performed using the Peng-Robinson thermodynamic model with a detailed three-phase flash separation module. Feed composition from the Somontepa gas field was used (CH_4: 89.65%; CO_2: 4.12%; H_2S: 3.00%; C_2–C_6+: 2.55%), at 5.6 MPa and 25 °C. The simulation accurately predicted the phase split, showing that 98.3% of the hydrocarbon vapor was directed to the gas outlet, while >99% of condensates and water were captured in the liquid phase. Sensitivity analysis across 20–65 m/s inlet velocities revealed that the pressure drop was reduced by 27% in the enhanced baffle configuration. Furthermore, Aspen Plus predicted a 96.8% decrease in entrained liquid carryover compared to a baseline separator. The results were validated through field trials, which confirmed the simulation predictions: gas condensate content was reduced from 16.58 to 0.725 g/m^3, moisture from 4.84 to 0.1 g/m^3, and mechanical impurities from 1.2 to 0.0058 g/m^3. This synergy of simulation and practice highlights the robustness of the improved design for deep natural gas decontamination and positions it as a scalable solution for industrial gas processing plants.

3.26. Molecular-Level Insights into Reinforcement Effects and Interface Chemistry in Graphene/Nickel Nanocomposites Under Tension—A Molecular Dynamics Study

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This study presents a comprehensive investigation of the uniaxial tensile behavior of graphene-reinforced nickel nanocomposites (Gr/Ni) using molecular dynamics (MD) simulations. Two distinct reinforcement architectures were examined: (1) a monolayer graphene sheet embedded within the nickel matrix (denoted **NiGr[−]**, ~0.66 vol%) and (2) a cross-shaped graphene network (denoted **NiGr[×]**, ~1.0 vol%). The mechanical response was evaluated under uniaxial tensile loading along the **z-axis**, considering three crystallographic interface orientations between graphene and nickel: **(100), (110), and (111)**.

The incorporation of graphene significantly enhances the mechanical performance of the nickel matrix, particularly in terms of **stiffness, strength, and ductility**. Specifically, the **Young's modulus** increased by approximately **123%** in the **NiGr[−]** configuration, while the **NiGr[×]** network further improved stiffness by **135%, 154%, and 143%** for the (100), (110), and (111) orientations, respectively. Similarly, the **ultimate tensile strength (UTS)** increased by **0.47 GPa, 3.61 GPa, and 4.97 GPa** in the **NiGr[−]** system and by **1.84 GPa, 6.24 GPa, and 10.62 GPa** in the **NiGr[×]** system for the same orientations.

The analysis revealed that the **NiGr[×]** configuration, particularly in the **(110) and (111)** orientations, exhibits the **most pronounced reinforcement effects**. Dislocation density mapping during deformation demonstrated that graphene acts as an **effective barrier to dislocation propagation**. Remarkably, the **NiGr[×]** structure enabled the composite to sustain a **strain level exceeding that of pure nickel by more than five times** before failure.

These findings highlight the **superior load-bearing capacity** and **enhanced structural integrity** of Gr/Ni nanocomposites, with the **cross-shaped graphene network** offering exceptional mechanical advantages. The results suggest significant potential for such architectures in **advanced engineering applications**, particularly in industries requiring **high-performance structural materials**.

3.27. Neutralization of Zearalenone by an Adsorption Feed Additive Based on Bentonite Clay Modified with the Bacterial Culture Bacillus subtillis

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Mycotoxins are harmful substances produced by mold fungi that may be present in livestock feed and food products. Bentonite clay, as well as feed additives based on bentonite clay, have proven their effectiveness and are known as adsorbents of toxins of various natures. Currently, a promising direction is the development of adsorption additives that include probiotics. Bacteria of the genus Bacillus have antifungal and antagonistic effects on phytopathogenic fungi.

Under sterile conditions, upon reaching the logarithmic growth phase of *Bacillus subtillis* KE1 VKM B-3705D microorganisms, sodium bentonite clay was added in a carrier:biomass ratio of 1:5, then lyophilized and stored at room temperature. The study was carried out by HPLC on an ACQUITY WATERS chromatograph with a BEH C18 reversed-phase column: eluent-gradient mixture (acetonitrile, water, methanol), 230–400 nm, 20 min, column temperature −40 °C; mobile phase flow rate 0.3 mL/min. The analyzed raw material was feed contaminated with an indigenous strain of the mold fungus *Fusarium* sp., the metabolite of which, is zearalenone. Zearalenone neutralization was assessed using the following scheme: on the 10th day after infection, 10.0 ± 0.1 g of contaminated feed were weighed into conical flasks, 10 mL of 1 M Tris-HCl (pH 7.5), 100 mL of distilled water and a weighed portion of the adsorption additive (0.10; 0.25; 0.50; 0.75; 1.00 g) were added. The flasks were placed in a shaker-incubator for 24 h at a T = 40 °C, then zearalenone was extracted and subjected to HPLC. A similar experiment was conducted with the sodium form of bentonite clay, produced by KalachBent LLC without a bacterial component.

It was found that an adsorption feed additive obtained from the sodium form of clay in combination with B.subtillis KE1 VKM B-3705D bacteria neutralizes the mycotoxin zearalenone in contaminated feed more effectively than the sodium form without the bacterial component.

3.28. New Approaches in the Quantification of Pure Ibuprofen in a Pharmaceutical by a Developed Spectrophotometric Ultraviolet (UV) Method

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Ibuprofen is a potent non-steroidal and anti-inflammatory drug derived from propionic acid, and its effects are brought about by the effective inhibition of the synthesis of both Cyclooxygenase isoforms COX-1 and COX-2. The main effects of ibuprofen are related to the effective control of moderate pain, acute inflammation and fever in many diseases such as *Patent Ductus Arteriosus*, dental pains, orthostatic hypotension, cystic

fibrosis, rheumatoid arthritis and osteo-arthritis. Ibuprofen is widely used to reduce mild and moderate aches and pains and reduce fever and manage dysmenorrhea. It is very commonly used for the relief of acute symptoms such as fever and tension headaches. It is also used to manage mild to moderate pain and moderate to severe pain as an adjunct to opioid analgesics. The main aim of this research was to exactly quantify pure ibuprofen in a pharmaceutical, using a new developed spectrophotometric method in the ultraviolet (UV) range. Maximum absorption wavelength was found at λ = 227 nm, corresponding to the absorbance of A = 0.7469, relative to absolute methanol used as a control. The amount of pure ibuprofen calculated in the pharmaceutical was 395.398 mg, corresponding to 98.85% percentage content, and was very close to the official reference value (400 mg). The average percentage deviation of the content found from the stated official amount (400 mg) was 1.15%, below the maximum percentage limit (±5%) allowed by the European and International Pharmacopoeias Rules.

3.29. Parametric Study of Slow Pyrolysis of Invasive Water Hyacinth for Energy Recovery Towards Cleaner Blue Carbon Technologies

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The urgent need for cleaner energy sources has driven exploration into innovative and sustainable solutions. This study investigates the potential of the invasive aquatic plant, the water hyacinth, to contribute to both energy recovery and blue carbon sequestration. Employing slow pyrolysis, an emerging technology for efficient biomass conversion, this study examines the influence of temperature (300–500 °C) and residence time (30–90 min) on the production of bio-oil and biochar from water hyacinth in a fixed-bed reactor. The results indicate that while the biochar yield (maximum of 43.74% at 400 °C, 30 min) was not significantly affected by the tested parameters, the bio-oil yield increased significantly with residence time. Maximum bio-oil yields of 34.34% and 34.03% were achieved at 400 °C and 500 °C, respectively, both with a 90-min residence time. The resulting bio-oil exhibited a high heating value of up to 25.84 MJ/kg, suggesting its potential as a renewable fuel. FTIR analysis identified functional groups within the bio-oil, indicating its suitability as a chemical feedstock. This study concludes that slow pyrolysis of the invasive water hyacinth offers a promising pathway for simultaneous energy recovery and blue carbon sequestration, contributing to a cleaner environment and a more sustainable future while also addressing the issue of invasive species proliferation. The dual benefit of waste management and renewable energy generation makes this a highly attractive approach for sustainable development, particularly in regions afflicted by water hyacinth overgrowth.

3.30. Properties of New Three-Component Hydrophobic Eutectic Solvents Based on BTMPPA

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Today, a pressing scientific task is the development of new solvents for extraction processes. One of the promising classes of solvents are hydrophobic eutectic solvents (HES), the main advantages of which are the ease of their production, low fire hazard and the ability to vary their properties by correctly selecting components. HES is often prepared

on the basis of two components—an extracting compound (e.g., TOPO, BTMPPA) and a so-called solvent (e.g., menthol, thymol). However, to improve the physicochemical and extraction properties of eutectic solvents, modifier components can be introduced. Studying the possibility of varying the properties of HES by changing their composition is a pressing issue today.

The aim of the present work is to study of properties of new hydrophobic eutectic solvents based on di(2,4,4-trimethylpentyl)phosphinic acid (BTMPPA), trioctylphosphine oxide (TOPO), metyltrioctylammonium chloride (MTOAC) and phenol.

The HESs were prepared from the main extractant (BTMPPA), modifier (TOPO/MTOAC) and "solvent" (phenol) in a molar ratio of 1:1:2. Based on the ^{1}H, ^{31}P NMR and IR spectroscopy data, a hydrogen bond formation in the proposed HESs was established. The physical properties of the proposed extractants were studied, namely, the dependence of density, viscosity and refractive index on temperature. The HES stability during interaction with water and mineral acid solutions was also studied. The viscosity of HES BTMPPA/TOPO/phenol reaches 64 mPa·s at 25 °C, which shows its potential applicability in technological processes. The proposed solvents were tested as extractants for Nd(III) and Dy(III) from nitrate solutions.

Thus, the promising use of HESs BTMPPA/(MTOAC or TOPO)/phenol in the extraction of rare earth elements from nitrate solution was shown. The obtained data can be used in the development of new effective hydrometallurgical processes of rare earth elements extraction from leaching solution of spent magnetic materials.

3.31. Synthesis and Characterization of Pani/Tio2 Composite for Photocatalytic Environmental Remediation

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Environmental pollution poses a significant global challenge. This work details the synthesis and characterization of polyaniline (PANI) and titanium dioxide (TiO_2) composite materials for their application in catalytic environmental remediation. The integration of PANI, a conductive polymer, with TiO_2 was aimed at enhancing the efficiency and broadening the applicability of TiO_2 in degrading various environmental pollutants. This work employed the approach of mechanochemical mixing of pre-synthesized PANI and TiO_2. The choice of synthesis method was critical to determine the surface area, porosity, and the degree of PANI encapsulation of TiO_2 particles. Composites are multifaceted, employing a range of analytical techniques. X-ray Diffraction (XRD) was used to confirm the crystalline phases of PANI/TiO_2. Pure polyaniline (PANI) has a 2theta value of 21.1(3), and after TiO_2 was incorporated into polyaniline, there was a shift from 21.1 degrees for PANI to 27.05 degrees for PANI-TiO_2, indicating an interaction between TiO_2 and polyaniline that alters their respective crystalline structures. Fourier Transform Infrared (FTIR) spectroscopy provided insights into the chemical interactions within the composite. The presence of

N-H, O-H, and C=N peaks confirms that both materials retain their essential chemical identities. Scanning Electron Microscopy (SEM) image of pure PANI revealed a fibrous structure, characterized by elongated fibers. TiO_2 particles were observed to be uniformly distributed within the PANI matrix. This distribution leads to a more compact structure compared to pure PANI, as TiO_2 particles fill in gaps between PANI chains, reducing porosity while increasing overall surface area. The synergistic effect between PANI and TiO_2 improved visible light absorption and efficient charge separation, overcoming the limitations of pure TiO_2. This research highlights the potential of PANI/TiO_2 composites as effective and sustainable photocatalysts for the degradation of organic pollutants in wastewater. Photocatalysis, utilizing semiconductor materials, offers a promising and sustainable approach for the degradation of pollutants into less harmful substances.

3.32. Synthesis of Benzene-1,2,4-Triyl Tris(2-(3-Carboxy-4-Hydroxybenzenesulfonate) Acetate)

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Benzene-1,2,4-triyl tris(2-(3-carboxy-4-hydroxybenzenesulfonate) acetate) synthesis is an important step forward in the synthesis of multifunctional organic molecules, which have potential uses in material science and medical chemistry, among other domains. In analytical chemistry, it can also be utilized for metal ion determination. This work presents a thorough and methodical approach to the synthesis of this complicated trisulfonated aromatic ester, emphasizing the effectiveness and scaling possibilities of the methodology. Choosing the right precursors to ensure that each one contributes to the intended molecular architecture was the first step in the synthesis process. In the initial stages of the synthesis process, oxyhydroquinone reacted with chloroacetyl chloride for 20 h. As a result, benzene-1,2,4-triyl tris(2-chloroacetate) of triatomic phenol-oxyhydroquinone was formed. The resulting phenacetyl chloride was reacted with sodium sulfosalicylate in the presence of DMFA. Benzene-1,2,4-triyl tris(2-(3-carboxy-4-hydroxybenzenesulfonate) acetate) was formed. To obtain high yields and purity, careful adjustment of the reaction conditions—including temperature, solvent selection, and reagent ratios—was required. The synthesized molecule was characterized using advanced spectroscopic techniques such as NMR, IR, and UV spectrometry, which confirmed its structural integrity and functional group configuration. Benzene-1,2,4-triyl tris(2-(3-carboxy-4-hydroxybenzenesulfonate) acetate), the resultant product, has special physicochemical characteristics. In particular, it is more soluble and has the potential to be a useful intermediate in organic synthesis. Because it has several reactive sites, preliminary research indicates that it may be useful in the development of new polymeric materials and as a possible ligand in coordination chemistry.

3.33. Separation of CO_2 and H_2S Mixture

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The separation and purification of carbon dioxide (CO_2) from sour gas streams is critical for emission reduction and industrial reuse. This study presents a chemical absorption-based process simulation of CO_2 and H2S separation using Aspen Plus, focusing on solvent-based treatment with several solvents. The process was modeled for two gas

streams originating from the Shurtan Gas Chemical Complex: a raw feed stream containing 3.42% CO_2 and 0.09% H_2S, and a treated dry gas containing 2.1% CO_2. The goal was to achieve high-purity CO_2 recovery ($\geq$99.5%) with flow rates of 30 t/h and 20 t/h, respectively. Rate-based modeling was employed to simulate mass transfer and chemical kinetics in the absorber and regenerator columns. The simulation results indicated that at optimal solvent flow and absorber temperature (40–45 °C), over 98.6% CO_2 and 99.9% H_2S removal could be achieved. The specific energy requirement for solvent regeneration was estimated at 2.3 GJ per ton of CO_2, aligning with industrial efficiency benchmarks. The purified CO_2 is intended for use in the production of sodium carbonate (Na_2CO_3) at the Dehkanabad Potash Plant, which converts 20 t/h of CO_2 into 296,000 tons/year of calcined soda with 77% process efficiency. This approach enhances gas resource utilization while reducing atmospheric emissions. The model serves as a techno-economically viable foundation for scaling up CO_2 capture and utilization (CCU) in the Uzbek chemical industry.

3.34. Slip Flow and Transport Characteristics of Jeffrey Fluid in a Compressed Channel Under Magnetic Field and Chemical Reaction Impacts

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This study investigates the effects of chemical reactions and viscous dissipation on the magnetohydrodynamic (MHD) squeezing flow of a non-Newtonian Jeffrey fluid confined between two parallel plates with velocity slip boundary conditions. Squeezing flows of this type are of significant practical importance in industrial and engineering processes such as lubrication systems, polymer extrusion, ink-jet printing, and biomedical applications involving fluid transport through narrow gaps. The governing nonlinear partial differential equations are reduced to a system of ordinary differential equations using similarity transformations and solved numerically via the Runge–Kutta method, implemented through the MPALE computational code. Validation of the results through comparison with previously published studies shows excellent agreement with key parameters such as the skin friction coefficient, Nusselt number, and Sherwood number. The results reveal that wall shear stress and axial fluid velocity increase as the plates move toward each other, intensifying the squeezing effect. An increase in the magnetic parameter and in the ratio of relaxation to retardation times leads to a reduction in velocity, temperature, and concentration. Viscous dissipation is found to enhance the temperature distribution and increase the heat transfer rate. Regarding mass transport, species-generating chemical reactions reduce the mass transfer rate, whereas species-consuming (destructive) reactions increase it.

3.35. Solvent Selection for Efficient CO_2 Capture

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Carbon capture is an essential technology for reducing industrial CO_2 emissions, particularly in the power and cement sectors. Among the various capture methods, solvent-based absorption systems are widely used due to their efficiency and scalability, making the selection of the right solvent critical for near-term applications. This study analyzes several solvents for use in an absorption-based CO_2 capture system, emphasizing identifying

the most suitable solvent for 2025–2030. The research methodology involves process modeling in Aspen Plus, sensitivity analysis, and evaluation of the regeneration duty for each solvent. The objective is to achieve at least 90% CO_2 capture and 95% CO_2 purity. The flue gas composition considered in this analysis is 19.8% CO_2, 9.3% O_2, 63% N2, 7.5% H_2O, and other trace gases. Various solvents are evaluated to determine their effectiveness in capturing CO_2 while minimizing the energy consumption during solvent regeneration. A sensitivity analysis was conducted to optimize the system's performance based on the solvent type, operating conditions, and regeneration duty. The results showed that amine blends demonstrated a CO_2 capture rate of 92% and a CO_2 purity of 96%, with regeneration energy requirements of around 3.2 GJ/ton of CO_2, significantly lower than those of traditional MEA systems, which typically require around 4.0 GJ/ton. In contrast, ionic liquids showed a CO_2 capture rate of 89% and a purity of 95%, with a regeneration energy of 2.8 GJ/ton, though their current cost is higher, limiting their immediate large-scale application. Annual capital expenditure (CAPEX) calculation revealed that amine blends could potentially reduce the CAPEX by 15–20% compared to MEA, while amino acid salts showed similar CAPEX reductions with a capture efficiency of 90%. Overall, the results indicate that hybrid amine solvents are the most cost-effective and practical solution for 2025–2030, with ionic liquids and amino acid salts emerging as promising alternatives as their costs decrease.

3.36. Structural–Functional Annotation, GO, PPI, Binding Sites, and Antigenicity Identification of an Uncharacterized Protein of Acinetobacter baumannii: A Computational Study

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Acinetobacter baumannii, an opportunistic human pathogen, targets critically ill patients as its primary target. *A. baumannii*, which was previously considered benign, is now recognized as a global hazard in the healthcare context. Its propensity to acquire multidrug, extensive drug, and even pan-drug resistance phenotypes at previously unanticipated rates is the primary reason for this. The objective of this investigation was to characterize the physicochemical properties, functional annotation, structure anticipation with active site determination, and antigenicity of the selected uncharacterized protein of *A. baumannii*. The protein's acidic nature was indicated by its putative pI (4.43), while its hydrophilicity was indicated by its GRAVY (−0.404). The functional annotation indicated that the protein was involved in catalytic reactions that led to the synthesis of L-asparaginyl-tRNA (Asn) and L-glutaminyl-tRNA (Gln). The protein was linked to both molecular functions and biological processes, as evidenced by the GO analyses. The protein's involvement with ten additional proteins was also demonstrated by the PPI network. The structural analyses demonstrated that nearly 50% of the residues were involved in the formation of an alpha-helix, while nearly 46.15% were involved in the formation of a random coil. The Swiss Model was found to be the most appropriate model for the uncharacterized protein in the 3D structural comparison. Furthermore, we quantified the active site's volume (4235.245 $Å^3$) and surface area (896.977 $Å^2$). The protein was identified as non-antigenic. In order to verify the results of this investigation, an experimental investigation should be implemented.

3.37. Synthesis of 2-Naphthyl 2-Chloroacetate and Study of Its Nucleophilic Substitution Reactions with Citric Acid

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The article analytically and experimentally presents the possibilities for the synthesis of 2-naphthyl 2-chloroacetate. Particular attention is given to the reaction conditions. Based on the literature review, the selective insecticidal activity and chemical properties of 2-naphthol, as well as the features of its nucleophilic substitution reactions with citric acid, are studied. The aim of the research is to develop an efficient method for the synthesis of O-chloroacetylated naphthol and to investigate the nucleophilic substitution reactions of the O-chloroacetylation product with citric acid. The chloracetylation of 2-naphthol in dichloroethane solution without a catalyst leads exclusively to O-acylation, resulting in the formation of 2-naphthyl 2-chloroacetate with a 95% yield. The composition and structure of the synthesized compounds were confirmed by spectroscopic methods. Since the reaction proceeds in dichloroethane without a catalyst, no acylium cation (ion pair) is formed. Therefore, the reaction follows a nucleophilic substitution mechanism at the carbonyl group of the chloroacetyl chloride molecule, yielding an ester product. The oxygen atom in the naphthol molecule serves as the nucleophilic reagent. The nucleophilic substitution products of 2-naphthyl 2-chloroacetate with citric acid were studied using thin-layer chromatography (TLC), and their composition was confirmed with reference substances. The physical constants of 2-naphthyl 2-chloroacetate were determined, and its composition and structure were verified using TLC, IR, and NMR spectroscopy.

3.38. The Fat Effect: A Systematic Review and Kinetic Meta-Analysis of Lipid Impacts on Food-Waste-Derived Bioethanol Fermentation

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As the global demand for sustainable fuels increases, bioethanol derived from food waste offers a double solution by producing renewable energy and reducing organic waste. However, food waste that is rich in lipids introduces a hurdle by inhibiting microbial fermentation, leading to reduced ethanol yields. This study seeks to evaluate the kinetic model that captures lipid-induced fermentation inhibition dynamics. A modified Monod–Andrews kinetic expression was employed to simulate microbial growth in the presence of lipids, particularly free fatty acids and triglycerides, to account for the non-linear relationship between substrate concentration and reaction rates. Parameters evaluated included the max specific growth rate (0.–0.5 h^{-1}), substrate concentration (which varied between 5 and 100 g/L), half-saturation constant (1–5 g/L), lipid inhibition constant (1–10 g/L), and lipid content (0–20%), as well as yield coefficient (0.45–0.51 g/g). The Monod–Andrews kinetic expressions were solved with the use of the ODE45s solver in MATLAB to address the kinetics of microbial growth and substrate consumption. A sensitivity analysis was performed on key variables to assess how input variables affect lipids in bioethanol production. Statistical validation metrics such as the root mean square error (RMSE) and coefficient of determination (R^2) were used to express the model's prediction accuracy, with an R2 of 0.9842 and an RMSE of 0.4948, showing its strong predictive capability. The results indicate

that lipid concentrations above 5–10% (*w*/*w*) reduce the ethanol yield by over 25%, with strong inhibition from free fatty acids. Simulated pre-treatment strategies improved the ethanol yield by 15–30%, validating the model's utility. This study delivers a scalable kinetic framework for predicting fermentation outcomes and optimizing bioethanol production systems that are rich in lipids.

3.39. The Formation Mechanism Ofpolysaccharide Hybrids of Glucuronoxylomannan with Embedded Gold Nanoparticles in Alkaline Medium

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Hybrid materials obtained through the synthesis of gold nanoparticles in the branched structure of a natural biopolymer, the polysaccharide glucuronoxylomannan (GXM), spontaneously form and demonstrate the highest stability in an alkaline environment. This is due to the fact that under these conditions, the ionisation of carboxyl groups leads to electrostatic repulsion of equally charged GXM fragments and the biomolecule 'tends' to form flexible, partially unfolded structures. In addition, polysaccharides undergo hydrolysis in an alkaline environment with gradual cleavage of monosaccharide links, starting from the reducing end of the polysaccharide (the so-called basic degradation of polysaccharides).

As a result of alkaline cleavage of heteroglycan, a shortened polysaccharide backbone is formed in the reaction mixture, and methasaccharide acids and unsaturated sugars are formed from the side chains, in the oligosaccharide residues of which acetyl groups are deacylated under the action of alkali. Alkali-induced hydrolysis leads to the growth of hydroxyl groups on small fragments, which in themselves can stabilise nanostructures, preventing their further growth, coalescence and dissolution. The presence of small and mobile polysaccharide fragments leads to a more rigid stabilisation of open fragments of spherical metal particles, on the one hand, and the formation of nanoparticles with triangular or quadrangular geometry, as we have shown for the case of monosaccharides. As a result, such hybrids have a dense and well-organised organic shell. A sufficiently large distance between metal nanoparticles and a solid layer of organic stabiliser makes the hybrid less prone to degradation over time. The report describes in detail the main mechanism of shortening the polysaccharide backbone due to alkaline degradation of polysaccharides and deacylation of the end fragments of the side chains. It also provides a brief overview of the results obtained by the authors for similar structures and suggests the most promising ways to use them.

3.40. The Use of Lanthanum-Based Intermetallic Compounds as a Catalyst in the Electrochemical Process of Ammonia Synthesis

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Introduction: Modern environmental challenges and the need to the decarbonization the chemical industry are stimulating an active research for alternative methods for the synthesis of ammonia, which is a key part for the production of fertilizers and a promising hydrogen carrier. In this case, electrochemical reduction of nitrates (NO_3RR) is of particular interest, which makes it possible not only to obtain a valuable product, but also to solve

the problem of wastewater treatment from nitrogen pollution. Recent studies demonstrate that intermetallic compounds (IMC) open up new possibilities for creating highly efficient catalytic systems for this process. In this work, for the first time, studies were conducted on the use of La-containing IMC as catalysts in the NO_3RR reaction.

Experimental: The samples (Cu-La and Co-La) were prepared using arc melting in an argon atmosphere at the AM-200 facility. Mass control of the samples after fusion showed that melting losses did not exceed 1 mass%. The physicochemical methods of characterization of La-IMC samples were used in the work: UV-vis spectroscopy, XRD. Linear voltammetry and chronoamperometry were used to determine the optimal conditions for the reactions and synthesis of ammonia, respectively. Autolab PGSTAT302N potentiostat and PS-20 potentiostat-galvanostat were used. The synthesis of ammonia and NO3RR tests were performed in alkali media for 1 h.

Results and Discussion: The results show that the use of electrocatalysts in the form of IMC is promising, since in the work carried out, high values of both the Faraday efficiency (FE) and the values of the ammonia yield rate were achieved. La and Cu compounds exhibit higher efficiency compared to IMC La based on Co.

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3.41. Transforming Goat and Rabbit Wastes into Sustainable Biochar for Enhanced Soil Health and Carbon Sequestration

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This study examined the pyrolytic synthesis, physicochemical characterisation, and applicability analyses of BC-based manure (or BCM) from goat droppings (GDs) and rabbit manure (RM). Dried raw materials of GDs and RM were pyrolyzed in a batch-operated drum kiln prolyser at a temperature of 600 °C for 30 min of residence/holding time. The BCM was then characterised to determine their physicochemical properties, which include the following; pH, total dissolved solids (TDS), oxidation–reduction potential (ORP), salinity (SAL), electrical conductivity (EC), and density (ρ). The results showed pH 8.84–9.60, TDS 192.15–708.21 mg/L, ORP 17.33–40 mV, SAL 156.67–570 ppm, and EC 315–1161 µS/cm. For all cases, the physicochemical properties of RM BCM were higher than the GD. On the other hand, the density of the GD BCM (683.33 kg/m^3) was higher than the RM (311.11 kg/m^3). The higher RM BCM values suggest higher available nutrients for improved soil health, whereas the higher density of GD BCM indicates a compact structure for enhanced stability in soils. Hence, RM BCM is better suited for soil enrichment, whereas GD BCM is better suited for soil structure conditioning and carbon sequestration. Overall, this study demonstrates the successful synthesis of BCM from RM and GD, which offers a practical sustainable waste management approach and improved agricultural soils for enhanced food production.

3.42. Valorising Pig Manure into Sustainable Biochar for Soil Enhancement and Carbon Sequestration Applications

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In this study, we examined the pyrolysis of pig manure (PM) wastes into biochar manure (BCM) for potential applications in enhancing soil structure, nutrient cycling, and carbon sequestration. PM-BCM was synthesised through pyrolysis in a batch-operated drum kiln pyrolyser at a temperature of 600 °C for 30 min of residence/holding time. Next, the PM-BCM was characterised to examine its physicochemical properties and utility potentials based on the following parameters: pH, total dissolved solids (TDS), oxidation–reduction potential (ORP), salinity (SAL), electrical conductivity (EC), and density (ρ). The results revealed the values pH 8.34, TDS 184.02 mg/L, ORP 126 mV SAL 149.33, EC 301.67 μS/cm, and ρ 1144 kg/m^3. Results showed that PM-BCM displays an alkaline pH, which could assist in neutralising acidity whilst boosting the soil microbial activities. EC and TDS revealed functional but balanced mineral ion contents suitable for enriching soils. ORP revealed that PM-BCM exhibits oxidative characteristics that could impact nutrient accessibility and microbial processes in soil systems, whereas SAL revealed controlled salt content. Moreover, the compact nature of the BCM, observed in its high density, indicates the potential for extended soil stability, sequestering carbon, and gradual nutrient delivery. Overall, the study reveals that PM-BCM is a low-cost, sustainable, and effective candidate for soil enhancement application.

4. Food Process Engineering

4.1. Integration of Fatty Acid Profiling and Mineral Analysis into the Sustainable Development of Algal-Based Functional Spreads

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Background: The growing demand for sustainable and health-promoting functional foods has led to the exploration of novel lipid sources. Algal oil, particularly rich in omega-3 long-chain polyunsaturated fatty acids (LC-PUFAs), offers a promising alternative to conventional fats. This study aims to integrate fatty acid profiling and mineral composition analysis into the development and optimization of an algal-oil-based chocolate spread, emphasizing its nutritional enhancement and potential health benefits.

Methods: A chocolate-based spread emulsion was developed using Schizochytrium sp.-derived algal oil as the primary lipid source. The formulation was optimized using response surface methodology (RSM) based on texture, spreadability, and sensory acceptability. Fatty acid methyl esters (FAMEs) were analyzed using Gas Chromatography–Flame Ionization Detection (GC-FID), while mineral composition was determined through Induc-

tively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The spread's physicochemical properties, including pH, moisture content, water activity, and oxidative stability (MDA assay), were also assessed.

Results: The optimized formulation exhibited high sensory acceptability, with a desirable spreadability index and stable emulsion properties. Fatty acid analysis revealed significant enrichment in docosahexaenoic acid (DHA, 37.64 ± 1.12%), followed by eicosapentaenoic acid (EPA, 12.08 ± 0.84%), indicating a strong omega-3 profile. Saturated and monounsaturated fatty acids were present in balanced proportions. Mineral analysis demonstrated elevated levels of magnesium (34.6 ± 2.3 mg/100 g), calcium (28.1 ± 1.7 mg/100 g), and iron (4.2 ± 0.3 mg/100 g), contributing to the functional benefits of the product. The final spread exhibited low malondialdehyde levels (0.78 ± 0.04 nmol/g), confirming oxidative stability during storage.

Conclusion: This study successfully demonstrates that the integration of fatty acid and mineral profiling into the product development phase enables the creation of a nutritionally dense and sustainable algal-based functional spread. The findings support the potential of algal oil as a viable alternative fat source in functional food formulations, with implications for cardiovascular and neuroprotective health outcomes.

4.2. Advanced Deep Learning Techniques for Shelf-Life Estimation and Food Waste Reduction

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The rapidly growing global population and evolving consumer preferences have intensified challenges in managing perishable food inventories and minimizing post-harvest losses. "Advanced Deep Learning Techniques for Shelf-Life Estimation and Food Waste Reduction" presents a comprehensive investigation into state-of-the-art neural network architectures and methodologies designed to accurately forecast the remaining usable life of fresh and processed food products. By integrating multimodal data sources—encompassing physicochemical quality indicators, environmental storage conditions, and real-world supply-chain variables—this research demonstrates how deep learning models can transform traditional shelf-life prediction and demand-planning practices, yielding substantial reductions in food spoilage and waste. Finally, we discuss broader implications for sustainable food systems and circular economy practices. By providing granular, product-level shelf-life insights, advanced deep learning enables more precise allocation of near-expiry goods to secondary markets (e.g., discount retail and food bank donations) and optimizes routing to minimize carbon emissions associated with spoilage-induced inefficiencies. Life cycle assessment (LCA) modeling of the pilot studies estimates a 7% reduction in greenhouse gas emissions per unit of food distributed, driven by lower waste volumes and reduced need for expedited transport of replaced stock.

In conclusion, this research substantiates that advanced deep learning techniques—particularly hybrid CNN-LSTM architectures integrated with reinforcement learning–driven decision systems—offer a transformative approach to shelf-life estimation and food waste reduction. The demonstrated improvements in predictive accuracy, operational waste savings, and environmental benefits underscore the potential for wide-scale adoption in commercial food supply chains. Future work will explore federated learning strategies to enable collaborative model training across organizations without sharing

proprietary data and the extension of these methodologies to additional food categories and distribution modalities.

4.3. Advanced Sustainable Food Processing: Ultrasound-Assisted Germination of Cucurbita pepo Seeds

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Introduction: The increasing demand for sustainable food technologies encourages the development of eco-friendly methods that optimize resource efficiency. Seed germination enhances nutritional and functional properties but is often time- and resource-intensive, especially in large-seeded species like *Cucurbita pepo*. This study integrates multiphysics simulation and experimental validation to evaluate ultrasound-assisted germination (UAG) as a green technology to improve germination efficiency by reducing water use, energy consumption, and germination time.

Methods: A multiphysics simulation was used to analyze the spatial and temporal thermoacoustic dynamics of the interaction between ultrasonic waves and seed structures. The simulation confirmed that temperature gradients did not exceed 60 °C, thereby preserving seed viability during treatment. *Curcubita pepo* seeds were treated experimentally with low-frequency ultrasound (40 kHz) at 1.5 MPa for 5, 10, 15, 20, and 25 min in an ultrasonic bath. A non-treated control group was included. Germination parameters, such as the germination rate and the germination index, were measured.

Results: The simulation verified effective stimulation without compromising viability. Ultrasound pretreatment significantly increased water uptake, reducing imbibition time and improving germination kinetics. The 10-min treatment produced the highest germination rate (47%) within 10 days, whereas the control group reached a maximum rate of 20% after 14 days. Additionally, measurements of water and energy consumption revealed that the 10-min treatment decreased water consumption by approximately 2000 mL and energy consumption by 1.63 kWh compared to those in the control group.

Conclusions: Combining multiphysics modeling and experimental results, ultrasound-assisted germination proves to be a promising sustainable method for large-seeded crops like Cucurbita pepo. It improves germination performance while reducing resource inputs and maintaining seed viability. This supports its application in sustainable food processing and environmentally responsible agriculture.

4.4. Alcoholic Fermented Cagaita (Eugenia dysenterica): Identification of Volatile Compounds

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Cagaita (*Eugenia dysenterica*), a native fruit of the Brazilian Cerrado, has high potential for the elaboration of fermented products due to its content of sugars and bioactive compounds. Alcoholic fermentation emerges as a promising alternative for the use of this raw material, resulting in beverages with differentiated sensory characteristics and added value. In addition, the study of the volatile compounds generated during the fermentation process is essential to understand the aromatic profile of the final product and its acceptance by the consumer. The objective of this study was to identify the volatile compounds present in the fermented juice of cagaita (*Eugenia dysenterica*). A sample of cagaita alcoholic ferment was filtered, properly stored and sent to the Laboratory of Extraction and Separation Methods (LAMES-UFG) in Goiânia-GO for the identification of volatile compounds by gas chromatography. Analyses were performed with 3 μL of the sample by Headspace in an Aglient gas chromatograph model 7890B coupled to a 7000D triple quadrupole mass spectrometer, equipped with a DB-WAX column (30 m × 250 μm × 25 μm). Five main compounds were identified: carbon dioxide (5.97%), acetaldehyde (0.94%), ethanol (89.08%), acetoin (1.73%) and phenylethylalcohol (2.28%). Ethanol was the major compound, accounting for approximately 89% of the volatile composition, followed by carbon dioxide and phenylethylalcohol. These results indicate that the fermentation process resulted predominantly in the production of ethanol, with the presence of other volatiles that may have contributed to the sensory profile of the beverage.

4.5. Antioxidant Capacity of Camellia japonica Leaves and Their Potential Role in Sustainable Food Packaging Solutions

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Plant-derived antioxidants have gained increasing attention due to their potential to enhance food preservation while promoting sustainability in packaging solutions. In this context, *Camellia japonica* leaves emerge as a promising source of natural antioxidant compounds with applications in functional foods and eco-friendly processing technologies. The antioxidant capacity of *C. japonica* leaf extract was evaluated using DPPH and ABTS radical-scavenging assays, which yielded IC_{50} values of 33.11 ± 7.25 μg/mL and 23.75 ± 10.97 μg/mL, respectively. Additionally, the total phenolic content (TPC), assessed by the Folin–Ciocalteu assay, was found to be 36.67 ± 4.05 mg GAE/g dry weight, reflecting a high concentration of polyphenolic compounds responsible for the observed bioactivity. These results suggest that *C. japonica* leaf extract possesses significant potential to inhibit oxidative deterioration, thereby supporting its incorporation into active food packaging

systems and as a natural food additive. The integration of such botanical antioxidants in food processing can offer multiple advantages, including extended shelf life, reduced reliance on synthetic preservatives, and improved maintenance of product quality and safety. Nonetheless, before large-scale industrial application, further studies are necessary to assess toxicological safety and possible sensory effects, ensuring consumer acceptance and regulatory compliance. Moreover, investigations into the interactions between the extract, food matrices, and packaging materials will be crucial to determine its practical feasibility. In conclusion, *C. japonica* leaf extract stands out as a promising natural antioxidant agent that aligns with sustainable food preservation goals, facilitating the development of environmentally friendly packaging and clean-label food products.

4.6. CFD-Based Modeling and Simulation of a Cabinet-Type Solar Dryer for Medicinal Plants

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This study presents a comprehensive computational and experimental investigation of a cabinet-type solar dryer specifically designed for the dehydration of Plantago major leaves, a widely used medicinal plant. A detailed three-dimensional transient model was developed using ANSYS Fluent to simulate airflow behavior, solar radiation heat transfer, and temperature distribution within the drying chamber under natural convection conditions, considering solar irradiance levels ranging from 600 to 850 W/m^2 and ambient temperatures of 28–35 °C. The initial CFD results revealed temperature gradients of up to 18.2 °C between trays and the formation of stagnant airflow zones, leading to uneven drying and significant moisture variation of up to 11.8% across trays. To address these limitations, the design was iteratively optimized by repositioning air inlets/outlets, integrating deflector plates, and adjusting tray spacing from 8 cm to 5 cm. The improved configuration resulted in a 25.4% enhancement in thermal uniformity (measured as standard deviation of tray temperature), a 22.1% reduction in total drying time (from 6.8 h to 5.3 h), and a 17.3% increase in overall energy efficiency. Experimental validation was conducted using 1.5 kg batches of freshly harvested Plantago major leaves, with moisture content monitored using gravimetric methods. The improved dryer reduced final moisture content variation between trays to less than 2.5%, ensuring more uniform drying and improved retention of bioactive compounds such as aucubin and flavonoids. These results confirm the predictive power of CFD modeling for solar dryer optimization and validate the practical benefits of the improved design. The integration of simulation and field data highlights the viability of deploying sustainable, energy-efficient, and low-cost drying solutions for medicinal plant processing, particularly in off-grid and rural communities.

4.7. Comparison of Drying Technologies for the Preservation of Tenebrio molitor Larvae

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In response to the growing global demand for sustainable food and feed sources, insects such as *Tenebrio molitor* (mealworms) have emerged as a promising high-protein alternative with a relatively low environmental footprint. Due to the relatively low water consumption in the rearing process, the smaller required area, and the nearly zero GHG emissions, mealworm proteins yield significant advantages over plant-based proteins. This study investigates the effectiveness and impact of various drying techniques on mealworm larvae, focusing on moisture reduction and the preservation of protein integrity. Freeze-drying, oven-drying at 40 °C and 60 °C, and fluidized/spouted bed-drying were each performed. Initial moisture content was measured using a Berghof/Germany EasyH_2O coulometer. Gravimetric analysis and differential scanning calorimetry (DSC) were employed to assess moisture loss and protein denaturation, respectively. The results indicate that freeze-drying and 40 °C oven-drying better preserved protein structures, whereas the 60 °C method led to more protein denaturation. Fluidized- and spouted bed-drying at 50 °C were explored as well. The spouted bed method demonstrated the best drying efficiency. However, the color and appearance of the product were nearly identical to those produced via the oven-dryingmethod at 60 °C, indicating similar conditions for a potentially unwanted Maillard reaction. Freeze-drying, though, preserved the color and structure of the product, in addition to the native protein content, which might add specific value to this method.

4.8. Development and Optimization of Apricot-Based Water Kefir Fermented Beverage: A Comprehensive Microbial, Physiochemical, and Proximate Evaluation

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Water-kefir is a known probiotic-rich fermented drink developed by the fermentation of sucrose using water kefir-grains. These grains contain beneficial lactic acid bacteria (LAB), acetic acid bacteria (AAB), and yeast. It helps in the improvement of gut health, digestion and immunity because of its high probiotic content. Apricot fruits contain vitamins like A, C, and E; fiber; as well as antioxidants that promote digestion, heart function and skin health. Apricot-based water kefir drink (AWKD) is a functional as well as novel drink that provides probiotics and vital nutrients, hence preserving the gut flora and health. The combination of both offers a healthier, more refreshing, and natural alternative to the standard probiotic drinks. The aim of this study was to optimize AWKD through response surface methodology (RSM) with a Box-Behnken design. Dried apricot juice (16.6–23.3% w/v) along with brown sugar (4–6% w/v) was fermented with water kefir grains (4.6–10% w/v) at 32 °C for 24 h. The impact of all three variables on pH, total bacterial load (CFU/mL), and overall acceptability (7-point hedonic scale) were examined to identify the optimal concentration of the product. The physicochemical, proximate, antioxidant and shelf-life analyses of the optimized AWKD were evaluated using AOAC international methods. The optimized concentration was found to be 8% (w/v) water-kefir grain, 8% (w/v) brown sugar and 20% (w/v) dried apricot, having a pH of 3.86, a total bacterial count 2.73×10^8 CFU/mL and the overall acceptability value of 6.89. This result suggested its profound potential as a functional probiotic beverage. This novel and innovative probiotics beverage may be a suitable substitute to vegan and lactose intolerant individuals.

4.9. Development of an Affordable Portable Ozone Gas Generator for Research and Education in Agricultural and Food Applications

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The growing demand from consumers for wholesome food products has made it extremely difficult to create eco-friendly and sustainable solutions. Ozone treatment in the food and horticulture product capitalization sectors has been widely acknowledged as completely safe for human use based on the most recent rules of the relevant authorities. Ozone devices for research and education are known to allow the introduction of ozone gas for many uses, especially in food and agricultural applications. Despite their usefulness, their expensive cost prevents them from being widely available in research and educational institutions in underdeveloped nations, which limits practical training and the creation of local applications to support the capacities of the food and agriculture sectors. At the same time, there has been a startling rise in electronic components worldwide, and the cheap prices have raised financial concerns. In this regard, the study's goal was to create a working prototype of an ozone (O_3) generator utilizing inexpensive parts. The apparatus was constructed utilizing a pump that delivers air at varying flow rates and a high voltage principal circuit that produced O_3. An Arduino board with sensors attached was used to accomplish the control operation. To finish the device, stainless steel tube and other basic components were utilized. Performance was assessed in accordance with the calibration procedure outlined for such produced devices or comparable ones. The findings provide credence to the viability of constructing an inexpensive ozone generator using inexpensive parts, hence promoting sustainable technological advancement.

4.10. Effect of Shredding Speeds on Efficiency and Shred Quality in a Motorized Makapuno Processing System

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The post-harvest mechanization of makapuno processing is key to improve efficiency and quality of the product. This study aimed to design, and evaluate an electric motor-driven makapuno shredder to enhance post-harvest processing. The makapuno shredder consists of a 186 W electric motor (1725 rpm), a V-belt and pulley transmission system, the shredding blade, and the framing system. A Completely Randomized Design (CRD) was conducted to evaluate the performance of the VMAC-1 makapuno variety under three shredding treatments: 35 rpm, 144 rpm, and through the manual shredder. The shredding

capacity (kg/hr), shred quality (% per class), and the total weight of shreds (g per 5 min) were the primary performance parameters.

Results revealed significant differences among treatments. The shredding capacities were 12.17 kg/h, 13.82 kg/h and 10.34 kg/h for 35 rpm, 144 rpm and the manual shredder, respectively. Additionally, the total weight of shreds after 5 min was 1151.27 g (144 rpm), 1014.03 g (35 rpm), and 861.20 g (manual), which confirms that higher rpm increases the output rate. However, in the shred quality analysis, it was revealed that 144 rpm resulted in over-shredding, leading to high proportion of finer shreds and reduce shred quality. This also resulted in 77.12% of shreds in Class C (low quality) and did not yield in Class A (high quality). Conversely, the 35 rpm speed produced highest percentage of Class B shreds with 52.70% that offers balanced optimization of the shredder. Although, manual shredder produces high-quality shreds, the 35 rpm setting provides better balance between efficiency and quality. Further improvement of the design of the shredding blade is recommended to match the quality of the manual shredder. Hence, the findings suggest the need to provide an optimized mechanized processing that contributes to sustainable and scalable makapuno production.

4.11. Effect of Reducing the Curing Period on the Quality of Salted Fish

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The salting process is considered complex due to several biochemical, physicochemical, and microbiological factors, which must be monitored to maintain product quality. The salting process in small agribusinesses is still carried out using the traditional method (dry or mixed salting), requiring an evaluation of the technology used to maintain quality. This study aimed to reduce the curing time of fish in tanks using the mixed salting method, ensuring the minimum quality characteristics recommended by law. The species marketed was chestnut (*Umbrina canosai*), and as a result, it was found that it is possible to reduce the curing time from 8 to 6 days, maintaining 30% salt in the tanks without affecting product quality. The pH and % absorption of NaCl were monitored during the curing period and the determinations performed were physicochemical for fresh fish (PF) and salted fish (PS): Total Volatile Bases (BVT), Trimethylamine (TMA), Thiobarbituric Acid Index (TBA), Peroxide Index (IP) whose results obtained for BVT = varied between PF and PS (24.2 to 27.40 mg/100 g sample respectively), TMA = for PF and PS (1.0 to 6.0 mg/100 g sample), TBA = for PS samples between the normal and reduced curing period (2.5 to 0.42 mg MA/Kg sample) and IP = for PS samples between the normal and reduced curing period (2.02 to 1.25 meq.peroxide/Kg sample). The product moisture results over 10 months of PS storage showed a reduction of 18%, in accordance with the legislation for the sampled batches. The results of the microbiological determinations were within the legislative standards for all determinations performed, reaffirming the possibility of reducing the curing period of fish in tanks, without losing the quality of the product and the process.

4.12. Fluidized Bed Reactor Design for Educational Purposes: A Popcorn Reactor Case Study

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Fundamental topics in chemical engineering such as fluid dynamics, heat transfer, and reactor design are often difficult for students to fully understand through theory alone. This paper presents a case study of a laboratory reactor developed as a hands-on teaching tool that integrates these key areas into a single, practical learning experience.

The designed and constructed laboratory-scale fluidized bed reactor employs popcorn production to illustrate a range of chemical engineering principles. It consists of the following:

- Vertical glass column.
- Thermocouple probe.
- Fluidized bed support grid.
- Air heater.
- Anemometer.
- Reinforced external casing.

In operation, hot air enters at the bottom, fluidizing the kernels while providing the energy and temperature needed for popping. Once popped, the kernels become lighter and larger, allowing the airflow to separate them from the unpopped kernels.

The reactor's development began by measuring the terminal velocities of unpopped kernels and popped popcorn to determine the minimum airflow for fluidization and separation. The effects of the airflow rate and heater power on air temperature were then examined to identify optimal operating conditions. Finally, popping times at various temperatures were tested to better understand the reactor's thermal behavior.

This setup effectively translates abstract theoretical concepts into intuitive, observable phenomena. By linking input conditions to real-time system responses, it enhances student comprehension and provides a solid foundation for advanced coursework.

4.13. Impact of Millet Adjunct on Physicochemical and Sensory Characteristics of a Non-Alcoholic Beverage from Malted Sorghum

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Malted sorghum (*Sorghum bicolor*) and finger millet (*Eleusine coracana*) are drought-tolerant grains widely available in Nigeria but remain underutilized in beverage production. Malt drinks, wholesome and non-alcoholic, are gaining popularity in the country. These local grains offer promising potential for sustainable beverage development. This study investigated the impact of incorporating millet as an adjunct on the physicochemical and sensory properties of a non-alcoholic beverage formulated from malted sorghum. Six beverage samples were formulated using malted sorghum and finger millet in the following ratios: 100:0 (S), 90:10 (SM1), 80:20 (SM2), 70:30 (SM3), 60:40 (SM4), and 50:50 (SM5). Standard analytical methods were employed to assess physicochemical parameters, including pH (4.71–4.88), °Brix (12.36–12. 77), density (1048.28–1049.68 kg/m^3), specific gravity (1.05018–1.05157), colour (180.05–200.15 HU), pasteurization unit (85.05–85.20 PU), bitterness (12.15–13.10 IBU), and alcohol content (0.065–0.105% ABV). The results showed millet inclusion did not compromise key quality indicators, with most values meeting industry standards. Density and specific gravity confirmed optimal extract concentration, while °Brix and bitterness supported an acceptable sensory balance. Although pH values were slightly above the ideal range for microbial inhibition, they indicated moderate acidity. Pasteurization units confirmed sufficient thermal processing for safety. Sensory evaluation showed no significant differences ($p < 0.05$) in appearance, aroma, taste, mouthfeel, or general acceptability among S, SM1, SM2, SM3, and SM4, except for SM5, which had signif-

icantly lower scores, especially in taste (3.67), aroma (4.40), and overall acceptability (2.60). The control (S) had the highest acceptability (6.53), followed by SM2 (6.13). Millet can serve as a viable adjunct in non-alcoholic beverage production using malted sorghum without adversely affecting physicochemical or sensory quality, particularly at inclusion levels up to 40%. This highlights the potential of using indigenous grains to reduce dependency on imported brewing materials and to enhance local crop utilization in developing regions like Nigeria.

4.14. Impact of Selenium Seed Priming on Emergence Rate, Selenium Accumulation, and Phytochemical Profile of Pea Microgreens

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Selenium (Se) is an essential micronutrient for human health, playing a crucial role in antioxidant defense and immune regulation as a key component of enzymes and proteins [1]. Although not essential for plants, small amounts of Se can benefit some species by improving their tolerance to environmental stresses [2]. Plants cultivated in Se-deficient soils naturally exhibited low Se levels, a concern expected to intensify with climate change. By the end of the century, 66% of croplands—including significant areas in Europe—are expected to face Se depletion [3], potentially exacerbating dietary deficiencies that already affect up to 1 billion people worldwide [3]. To counteract this, the use of Se-containing fertilizers has been proposed as a possible solution. This study explored the biofortification of pea (*Pisum sativum* L.) microgreens through Se seed priming, a cost-effective and environmentally friendly technique that enhances germination uniformity and seedling vigor. Seeds underwent nutripriming with sodium selenate (25–100 μM Se) for 6 and 12 h, with hydroprimed and unprimed seeds serving as controls. After treatment, one batch of seeds was analyzed for electrolyte leakage, while another was sown to evaluate germination dynamics and biomass accumulation. Upon harvest, Se content was quantified using atomic absorption spectroscopy, alongside analyses of chlorophylls, soluble sugars, organic acids, total phenolics, and antioxidant activity [4,5]. The results showed that Se nutripriming improved membrane integrity by reducing electrolyte leakage in pea seeds. The treatment influenced the emergence and growth of microgreens. The 6 h priming treatment led to superior agronomic performance and biomass accumulation compared to the 12 h treatment, though unprimed seeds exhibited the highest emergence rate and consequent biomass production. Nonetheless, nutripriming increased Se concentration in microgreens. These findings underscore the need to optimize priming protocols to enhance both seedling emergence and Se uptake, offering a sustainable strategy for developing Se-biofortified crops to address global nutritional deficiencies in the context of climate change.

4.15. Nature-Inspired Approaches for Optimizing Food Drying Processes

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Food drying has an impact on the final product's quality, energy usage, and environmental sustainability, making it a crucial step in food preservation. Although crucial,

traditional optimization methods usually fall short in the complex, nonlinear, and multi-objective process of food drying. Algorithms inspired by nature that simulate biological, chemical, and physical systems have become popular tools for enhancing these procedures; they perform better when faced with multiple variables and conflicting objectives. The application of nature-inspired optimization techniques, including artificial neural networks, genetic algorithms, particle swarm optimization, and the non-dominated sorting genetic algorithm II, to food drying is critically examined in this work.

The main focus of the study is on the theoretical foundations of these algorithms, their specific application in food drying, and the benefits and drawbacks of each method. Furthermore, we examine recent case studies that demonstrate the practical use of these strategies in food processing plants to enhance environmental impact, energy efficiency, and product quality. The findings imply that if these advanced optimization algorithms are included into computer-integrated production systems, the food drying industry may embrace more cost-effective and ecologically friendly procedures. The scalability of these technologies for industrial applications is also critically assessed, exposing practical challenges and providing suggestions for future research directions. This in-depth examination seeks to serve as a helpful tool for experts and academics curious in the food dying optimization, presenting insights that are board and deep, suitable for a multidisciplinary audience.

4.16. Process Optimization of a Novel Synbiotic Maize-Based Spread: Response Surface Methodology Approach

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Introduction: In recent years, synbiotics have gained popularity as consumers seek natural, scientifically supported ways to maintain health and prevent diseases. Synbiotics consist a blend of probiotics and prebiotics. Yogurt, a probiotic-rich dairy product, and maize, rich in fiber content, specifically in the form of soluble fiber (inulin), which promotes prebiotic properties. This provides a synergistic base for developing value-added foods. In the current study, an attempt was made to formulate a maize-flavored yogurt spread (MYS).

Methodology: Response surface methodology (RSM) was used to optimize the formulation of MYS. Twenty-nine formulations, with varying levels of independent variables, viz., yogurt (55–65%), maize flour (25–35%), seed mix (4–6%), and herb mix (4–6%), were processed using a Box–Behnken Design (BBD). The dependent variables were moisture content, pH, total bacterial count (TBC), and overall acceptability. Further, the optimised MSY was estimated for physiochemical, nutritional, and antioxidant properties using AOAC methods.

Results: The optimized MYS attained a good range of total bacterial count, 2.2×10^8 CFU/mL, protein, 9.01%, fat, 8.07%, DPPH antioxidant potential, 60.58%, and total phenolic content, 73.39%, compared to control ($p < 0.001$). Moisture content (17.19%) and acid value (0.32%) comply with the FSSAI guidelines for fat spreads. Also, the product was prepared with natural ingredients, without any addition of artificial additives or sweeteners.

Conclusions: MYS demonstrated significantly higher nutritional, antioxidant, and sensory properties, attributing to high consumer appeal. Thus, MSY has the potential for industrial exploitation as a promising functional food product.

4.17. Processing of Gluten-Free Cupcakes Utilizing Plant-Based Lepidium sativum Seed Mucilage as a Fat Replacer

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Introduction: Consumers are sticking to nutritional guidelines on fat consumption and demanding healthier gluten-free food products, resulting in pressure on industries to produce such food products. This study aims to develop the process of making gluten-free cupcakes by substituting wheat flour with a gluten-free composite flour blend and traditional butter with seed mucilage.

Methods: Gluten-free cupcakes (GFCs) were developed using the composite flour blend (amaranth, barnyard, and soyabean flours at 1:1:1). *Lepidium sativum* seed mucilage (LSM) mimics fat's properties; it was extracted using centrifugation–separation technology. The GFCs were optimized through a one-factor at a time (OFAT) optimization technique to see the effect of LSM as a single variable when used in different proportions: 0%, 25%, 50%, 75%, and 100%. The 100–fat-replaced GFCs were further evaluated for moisture, ash, protein, fat, fiber, and carbohydrate content (AOAC 2023), fatty acid profiling (GC-FID), and sensory evaluation (on a 9-point hedonic scale), and various health lipid indices were also calculated.

Results: The replacement of 100% fat in the GFCs shows a reduction of 88.74% in fat. The optimized product has moisture% = 26.31 $\pm$ 0.07, ash% = 1.45 $\pm$ 0.13, protein = 8.43 $\pm$ 0.07 gm/100 gm, fat = 2.19 $\pm$ 0.23 gm, fiber = 4.28 $\pm$ 0.12 gm, and carbohydrate = 39.83 $\pm$ 0.09 gm. The fatty acid profiling comparison of GFCs with butter and 100% of the fat substituted shows values for UFA:SFA = (2.3:1)(1.95:1), PUFA:SFA = (0.66:1)(1.02:1), and omega 6:omega 9 = (0.34:1)(1.1:1), respectively. An optimized GFC has an atherogenicity-index = (0.78), a thrombogenic index = (1.06), a health-promoting index = (1.36), and a Δdesaturase-index = (16) (0.022), which indicates good values, while the overall sensory acceptability is 8.2 $\pm$ 0.21.

Conclusion: This study indicates that optimized GFCs with incorporated composite flour and 100% of the fat replaced by LSM had an improved overall proximate, sensory, and nutritional matrix. Thus, the results demonstrate the possible potential of these ingredients to improve functionality, consumer acceptance, and industrial applications.

4.18. Progress in Particle Engineering to Improve the Overall Quality and Functionality of Bioactive Compounds in Functional Drinks

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There is considerable interest in the use of naturally derived bioactive compounds (BACs) in the formulation of fortified functional drinks, owing to their health benefits. Yet, industrial scalability raises several challenges, mainly due to their instability in response to external factors such as pH, light, oxygen, temperature, and sugar content. BACs such as vitamins, carotenoids, polyphenols, amino acids, coenzyme Q10, and pre-/probiotics are susceptible to degradation during processing and packaging, which can reduce their effec-

tiveness. In this context, this systematic review aims to study the use of particle engineering as technological means of optimizing these parameters through techniques including nano- and microencapsulation, and high-pressure homogenization. The methodology used is to collect data from relevant databases, such as PubMed and ScienceDirect, and then clean and refine the data using the keywords "particle engineering," "bioactive compounds," and "functional beverages." The year of publication is also limited, and various bibliometric methods are applied. The results show that these methods protect the BACs, boost their solubility, control their release, and preserve their stability in complex liquid matrices. Additionally, factors such as sugar type and quantity, fermentation temperature, and storage time can greatly impact the stability and bioavailability of these compounds. The growing demand for natural products and low-calorie, healthy functional drinks is driving extensive research on optimizing novel ingredients for these trendy beverage categories. In conclusion, this study critically analyzes the technologies used to engineer particles in functional drinks, focusing on how they impact the stability, bioavailability, and effectiveness of BACs, as well as their capacity to optimize the overall quality, food safety, and commercial viability of these items in the food and nutraceutical markets.

4.19. Removing Microplastics from Table Salt Solutions Using High-Surface Biochars

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The pollution of the aquatic environment by microplastics has been extensively studied; however, data on their presence in commercial salts widely consumed around the world remain limited. Most people consume foods containing a significant amount of salt throughout their lifetime. Therefore, its consumption is a long-term route of exposure of microplastics to the human body, and it can lead to negative health effects. Previous studies have shown that 94% of the salt products tested worldwide contain microplastics, with fragments and fibers being the prevalent types of particles and polypropylene (PP), polyethylene (PE) and polyethylene terephthalate (PET) being the most abundant polymer types. Therefore, this study focuses on the presence of microplastics in table salt products purchased in Greece. Samples from various brands and sources were analyzed using a combination of metallic sieves and stereomicroscopy to assess particle size, color, and morphology. Blank analyses were conducted to eliminate the possibility of internal cross-contamination. Furthermore, microplastic types were identified using chemical pretreatment and advanced spectroscopic techniques, including Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy. Then, batch experiments were employed to study the removal of PE with a diameter of 10 μm from water using different types of biochars. In particular, the results indicated that biochar synthesized from grape seed exhibits better microplastic removal than biochar derived from rice husk. This improved removal process is attributed to the enhanced porosity and surface area of the grape seed biochar.

4.20. Supercritical Fluid Extraction from Chamomile Flowers from Tarma, Peru: Yield, Kinetics, and Composition

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Chamomile is a source of bioactive compounds. In the province of Tarma, Peru, chamomile is commercialized for use in traditional medicine and tea-making. The present study aimed to obtain chamomile flower extracts (CFEs) using supercritical CO_2 (200 bar and 40 °C) and to analyze their composition. Chamomile flowers produced in Tarma were used in the extractions. The CFE was collected into a flask adapted for weight control during the supercritical fluid extraction (SFE) process. The CFEs were analyzed using gas chromatography coupled to a mass spectrometer (GC-MS) to determine their composition. A yield of 2.8 ± 0.3% CFE was obtained after 122 min of extraction with a CO_2 flow rate of 5.38 g/min. During the SFE extraction process, a colorless extract with an aroma characteristic of chamomile flower essential oil was initially obtained, followed by an amber-colored extract with an oily texture and aroma characteristic of chamomile. According to the behavior of the extraction kinetics, it is likely that part of the colorless extract was volatilized with the solvent flow during the process. The CFE presented 57 chemical compounds, with the most abundant being 4-(4-Hydroxy-2,2,6-trimethyl-7-oxabicyclo[4.1.0]hept-1-yl)butan-2-one (12.86%), (Z)-2-(Hexa-2,4-diyn-1-ylidene)-1,6-dioxaspiro[4.4]non-3-ene (11.82%), 2,6,10,10-Tetramethyl-1-oxaspiro[4.5]decan-6-ol (11.54%), pentacosane (8.07%), cyclohexanethiol, 2,5-dimethyl-, acetate (5.61%), and tetracontane (5.26%). The CFE obtained using supercritical CO_2 has an interesting composition of bioactive compounds, requiring further studies for its application in the food and pharmaceutical industries.

4.21. The Acidity as a Quality Parameter of Acidophilic Milk Enriched with Honey and Protein Supplements

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One of the most interesting fermented milk products with functional properties is acidophilus milk. It is well known that the nutritional value, therapeutic properties, and rheological characteristics of these products can be enhanced by incorporating various supplements. The objective of this study was to investigate the duration of fermentation and the change in pH value and acidity during 14 days of storage in supplemented acidophilus milk. The samples of milk with added honey (1% *w*/*w*) were additionally supplemented with whey protein isolates of cow origin at 0.5% (*w*/*w*) and 1.5% (*w*/*w*) concentrations, or with whey protein isolates of goat origin at 0.5% (*w*/*w*) or 1.5% (*w*/*w*). A lyophilised bacterial culture of *Lactobacillus acidophilus* (LA-5) was used for direct inoculation into milk. So, five different acidophilus milks were prepared. According to the research results, the endpoint of fermentation was reached in intervals of 7 to 13 h. The time required to target a pH of 4.60 ± 0.05 was shortened by 38% with the addition of 1.5% (*w*/*w*) whey protein isolate of cow origin. On the 14th day of storage, decreases in pH values were observed in every sample of prepared acidophilus milk. During storage, there were no significant

changes in the lactic acid content in prepared supplemented acidophilic milks, except for the sample with added 1.5% (*w*/*w*) whey protein isolate of goat origin. This supplemented acidophilus milk showed an increase in lactic acid content and a statistically significant difference ($p < 0.05$) compared to the other samples, as well as the results at the 1st and 7th storage days. Compared to other published results, the prepared supplemented acidophilic milks showed fair stability of pH and lactic acid during 14 days of storage.

4.22. The Effects of Humic Acid and Salinity Stress on the Growth and Biochemical Responses of Basil Microgreens

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Microgreens are increasingly popular due to consumer demand for healthier foods and a shift toward sustainable agriculture, especially in saline-affected areas. Humic acids (HAs) have shown potential in enhancing nutrient uptake and improving plant resilience under stress. This study evaluated the effects of salinity stress (0–80 mM sodium chloride, NaCl) and HA (0–5 g/L) on the growth and phytochemical composition of basil (*Ocimum basilicum* L.) microgreens. Seeds were sown in vermiculite-filled trays and grown under greenhouse conditions, with a 6-day dark germination period. Salinity and HA treatments were co-applied via irrigation from sowing until harvest (15 days after sowing). Growth parameters (height and colour) were recorded. Chlorophylls, organic acids, tocopherols, fatty acids, and minerals were analyzed using chromatographic and spectroscopic techniques. Total phenolic content (TPC) and total flavonoid content (TFC) were determined colorimetrically, and antioxidant activity was assessed using the thiobarbituric acid reactive substances (TBARS) and oxidative hemolysis inhibition assay (OxHLIA). Eighteen fatty acids, three tocopherols, and five organic acids were identified. Salinity and HA significantly affected most chemical parameters ($p < 0.05$), though plant height and colour were unaffected. Microgreens treated with 40 mM NaCl and 3.5 g/L HA accumulated the highest mineral content (2.86 g/100 g fresh weight). The highest TFC (0.4 mg of quercetin equivalents/g extract) was observed with 40 mM NaCl and 1.5 g/L HA, while the highest TPC (7.3 mg of gallic acid equivalents/g extract) occurred at 0 mM NaCl and 5.0 g/L HA. The strongest antioxidant responses were recorded in samples treated with 40 mM NaCl plus 5.0 g/L HA (OxHLIA, IC_{50} = 28.8 μg/mL) and 0 mM NaCl plus 2.5 g/L HA (TBARS, EC_{50} = 45.2 μg/mL). HA likely promoted osmotic adjustment, enhancing nutrient uptake and antioxidant defense, supporting better phytochemical profiles under stress. Its effects were most notable under moderate salinity.

5. Process Control and Monitoring

5.1. A Fuzzy Cascaded FOPI-FOPD Controller Optimized by TLBO for Nonlinear Temperature Control in CSTH Systems

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Precise temperature regulation in nonlinear and highly dynamic systems—such as the Continuous Stirred-Tank Heater (CSTH)—poses significant control challenges due to internal nonlinearities, time-varying dynamics, and external disturbances. Traditional linear controllers often fall short in addressing these issues effectively. To overcome these limitations, this paper proposes a novel Fuzzy Logic Control (FLC) strategy tailored for CSTH temperature regulation. The proposed controller features a hybrid structure that combines a Fuzzy Fractional-Order Proportional-Integral (FOPI) controller cascaded with a Fractional-Order Proportional-Derivative (FOPD) compensator, forming a Fuzzy FOPI-FOPD control scheme. This configuration harnesses the strengths of fuzzy logic for handling uncertainty and nonlinearity. To optimize the controller's parameters, various metaheuristic algorithms are employed, with a primary focus on the Teaching-Learning-Based Optimization (TLBO) technique. The Integral Time Absolute Error (ITAE) is used as the performance index to implememt the optimization process, ensuring effective minimization of tracking error over time. Extensive simulation studies are conducted under different operating conditions, including setpoint variations and external disturbances, to validate the effectiveness of the proposed method. Comparative analysis reveals that the Fuzzy FOPI-FOPD controller outperforms conventional control strategies in terms of transient response, steady-state accuracy, and robustness. Specifically, the controller exhibits reduced overshoot, faster settling time, and improved disturbance rejection. These results highlight the controller's potential for practical deployment in industrial thermal processes. Overall, the proposed optimization-based fuzzy fractional-order control framework offers a highly effective and flexible solution for complex nonlinear process control applications.

5.2. A Novel Security Index for Assessing Information Systems in Industrial Organizations Using Web Technologies and Fuzzy Logic

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Industrial information systems leveraging web technologies, ISOWT, face escalating security challenges, particularly in critical sectors like energy. Traditional qualitative assessments often fail to provide actionable, real-time insights for managing complex, dynamic threats. This paper introduces a novel security index for evaluating ISOWT in industrial organizations, integrating fuzzy logic, metric-based evaluations, fuzzy Markov chains, and multi-agent systems. The index quantifies deviations from an ideal "center of safety," enabling early risk detection and proactive mitigation. Validated through case studies on Syria's energy sector systems—namely, the Ministry of Electricity website and Mahrukat fuel management system—the methodology achieved significant improvements, including a 45.9–58.5% increase in the security index, 56.9–60.3% reduction in page load times, and 78.3–82.4% decrease in vulnerabilities. Compared to existing methods, this approach offers superior quantitative precision, real-time monitoring, and predictive capabilities. This scalable, automated framework addresses critical gaps in ISOWT security assessment, providing a robust tool for enhancing system resilience. Its adaptability makes it applicable across diverse industrial contexts, contributing to advanced cybersecurity practices for critical infrastructure. Future work will focus on integrating advanced technologies, expanding applications to other sectors, developing adaptive fuzzy models, addressing human factors, and enhancing visualization capabilities. These advancements will further strengthen the methodology's impact and address the evolving security challenges faced by industrial organizations in an increasingly connected world.

5.3. A Real-Time Model Predictive Control Framework for Enhanced Process Monitoring in Industrial Chemical Reactors

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In modern industrial environments, efficient process control and monitoring are critical to ensuring optimal performance, safety, and product quality. As chemical and manufacturing processes become increasingly complex and nonlinear, traditional control techniques such as Proportional-Integral-Derivative (PID) controllers exhibit limited adaptability and robustness in the face of dynamic operating conditions, disturbances, and system uncertainties. This paper proposes a real-time integrated control and monitoring framework based on Model Predictive Control (MPC) and an Extended Kalman Filter (EKF) for fault-tolerant regulation of chemical reactors. The MPC component predicts future system behavior over a finite horizon and optimizes control inputs while respecting operational constraints. In parallel, the EKF provides accurate state estimation and residual analysis for anomaly detection and real-time health monitoring. The proposed methodology is applied to a benchmark nonlinear system—a continuously stirred tank reactor (CSTR)—to evaluate its effectiveness. Simulation results demonstrate superior performance of the MPC-EKF framework in terms of setpoint tracking, disturbance rejection, fault detection speed, and energy efficiency, compared to conventional PID control. Notably, the system can detect and respond to abrupt faults, such as flow disruptions, within a few seconds, thus minimizing process deviations and operational risks. The findings highlight the potential of combining predictive control with model-based monitoring for next-generation smart process systems and industrial digitalization initiatives.

5.4. A Fuzzy Logic-Based Temperature Prediction Model for Indirect Solar Dryers Using Mamdani Inference Under Variable Weather Conditions

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The drying process in indirect solar dryers, which is strongly affected by rapidly changing ambient conditions, represents a highly nonlinear and dynamic system. Accurate modeling is essential for performance evaluation, process optimization, and reliable prediction of drying chamber temperature, which is crucial for ensuring efficient moisture removal while maintaining the nutritional and sensory quality of dried products. In this study, a fuzzy logic-based modeling approach using the Mamdani inference system was developed to predict the drying chamber temperature under a wide range of operating conditions. Experimental measurements were performed with solar radiation varying from 400 to 950 W/m^2 and the ambient temperature ranging from 20 to 50 °C, covering both static and dynamic system responses. The fuzzy model inputs consisted of solar radiation and ambient temperature, represented by five triangular membership functions (“very low,” “low,” “medium,” “high,” and “very high”) for solar radiation, and three triangular membership functions (“cold,” “warm,” and “hot”) for ambient temperature. The output variable (drying chamber temperature) was modeled with five triangular membership functions (T1–T5). The Mamdani system employed 15 “if–then” rules, and the centroid method was used for defuzzification. Model validation was conducted across the full range of operating conditions, showing strong agreement between predicted and experimental data. For instance, at 700 W/m^2 and 46 °C, the predicted temperature was 50.9 °C versus a measured temperature of 51.0 °C, while at 750 W/m^2 and 50 °C, the prediction

(52.0 °C) closely matched the experimental value (51.8 °C). Statistical evaluation yielded RMSE = 0.38 °C, MAE = 0.29 °C, and R^2 = 0.997, confirming high accuracy and robustness. These results demonstrate that Mamdani fuzzy logic can effectively model the thermal behavior of solar dryers under diverse climatic conditions, and they provide a solid basis for developing real-time intelligent control strategies to optimize energy efficiency and product quality.

5.5. ANFIS-Based Intelligent Control of Chlorine Removal in the Industrial Wastewater Treatment Process

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The intelligent control of industrial wastewater treatment processes, especially for the removal of residual chlorine ions, is crucial for ensuring environmental safety, protecting infrastructure from corrosion, and optimizing operational efficiency. In this study, an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based control model was developed and implemented for real-time control of a laboratory-scale activated carbon filtration unit. The primary objective was to dynamically regulate the chlorine removal process by adjusting the influent flow rate and activated carbon dosage based on predicted output parameters. The ANFIS model was trained using a dataset of 200 experimental trials that encompassed six key process variables: flow rate (m^3/h), initial chlorine concentration (mg/L), system pressure (bar), pH, temperature (°C), and activated carbon dose (kg). These six parameters served as input variables, while the output control targets included residual chlorine concentration (mg/L), energy consumption (kWh), and overall system efficiency. The designed ANFIS controller actively modulated the flow rate and carbon dosage in response to changes in initial chlorine concentration, temperature, and pH, thereby ensuring optimal chlorine removal under varying conditions. Compared to a traditional Proportional–Integral–Derivative (PID) controller, the ANFIS-based system demonstrated superior performance in dynamic tracking, disturbance rejection, and steady-state regulation. Specifically, ANFIS achieved a 72.4% reduction in steady-state error, decreased settling time by 2.7 s, and enhanced overall prediction accuracy, as confirmed by regression values exceeding 0.96. Additionally, optimized control actions by ANFIS led to a 1.6% reduction in energy consumption compared to PID, contributing to more sustainable process operation. These results confirm the efficacy of ANFIS in handling nonlinear, multivariable industrial processes and highlight its potential for integration into full-scale intelligent supervisory control systems such as SCADA. The research demonstrates that the hybrid use of neural networks and fuzzy inference provides a flexible, data-driven solution for real-time control in industrial water treatment applications.

5.6. Adaptive Fuzzy Control of Petroleum Extraction Columns Using Quantum-Inspired Optimization

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The automation of petroleum extraction columns requires robust and adaptive control due to the highly nonlinear nature of the heat and mass transfer processes involved. In this study, a hybrid control system integrating conventional fuzzy logic with quantum-inspired computational optimization is proposed to enhance the control of temperature

and flow rates in industrial extraction columns. Unlike classical fuzzy controllers that rely solely on expert-defined rules, our approach utilizes a quantum-inspired optimization algorithm to adaptively refine fuzzy rule weights based on performance feedback. While the physical quantum effects at macroscopic industrial scales are negligible, the proposed method emulates the computational advantages of quantum systems, such as parallel rule evaluation and probabilistic amplitude processing, in a classical environment. A MATLAB/Simulink-based simulation model of the extraction column was developed to validate the approach. Experimental tests were conducted under controlled conditions using synthetic data and varying operational parameters to measure improvements in control performance. The hybrid controller achieved a 0.7% reduction in phenol consumption and reduced temperature deviations by 2.2% compared to a baseline fuzzy controller. Energy savings ranged from 1% to 2% depending on operating scenarios. These results were supported by repeated simulations and statistical analyses across multiple testing cycles. The proposed system demonstrates the potential of quantum-inspired fuzzy control to enhance process efficiency, reduce energy use, and improve product quality in complex chemical extraction applications.

5.7. Application of Reduced Graphene Oxide in the Photolithography Process of Biodegradable Composite to Improve Its Electrical Conductivity

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Introduction: The combination of single-walled carbon nanotubes (SWCNTs) and reduced graphene oxide (rGO) in the photoresist minimizes the amount of carbon particles. While developing neuroimplants designed to restore damaged neural networks or modulate pain transmission, the key requirements are both biocompatibility and electrical conductivity.

Methods: Photolithography of the composite was performed with an ytterbium laser at a wavelength of 1035 nm with pulses of 100 ns duration, repetition rate of 30 kHz and power of ~550 mW. The photoresist used was SWCNT 0.6 mg/mL, rGO 0.6 mg/mL and SWCNT (0.3 mg/mL)/rGO (0.3 mg/mL). The final biohybrid structure contains proteins, chitosan and eosin Y. The formation of the structure was simulated by the molecular dynamics method with SEM monitoring.

The specific electrical conductivity of 15 5 $\times$ 5 mm layers was determined using the four-probe method. Biodegradation was estimated by the mass of the swollen sample in an isotonic sodium chloride solution and dried, with the following enzymes: lipase—25,000 PhEur; amylase—18,000 PhEur and protease—1000 PhEur. In vitro biocompatibility studies were conducted with the Neuro 2A cell line with the MTT test for 72 h.

Results: Specific conductivity: 17 mS/cm (rGO), 19 mS/cm (SWCNT) and 35 mS/cm (SWCNT/rGO). The mass loss of the SWCNT/rGO sample was 40%, the swelling increased by 20%, and the optical density (OD) of the MTT test was 0.76. Control cover glass OD = 0.62. Enzymes degraded the sample in a week. Simulation and SEM confirmed laser-induced rearrangement of SWCNTs with RGO into single nanostructures with the formation of non-hexagonal carbon elements.

Conclusions: The composite developed in the process of degradation can be replaced by biological tissue during this period with the maintenance of electrical conductivity.

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5.8. Contribution of Energy Storage System to Enhance Power System Voltage and Frequency Stability in Presence of Distributed Generation Units

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In power systems, the main control mechanism responsible for maintaining the grid frequency and voltage at their nominal values and the exchange of real power between balancing zones at the programmed values is called automatic generation control (AGC). The load frequency control loop named LFC controls the real power and frequency, while the automatic voltage control loop called AVR controls the reactive power and voltage. Variations in power demand disrupt the balance between active and reactive power, thus causing frequency and voltage deviations from the nominal values. Therefore, it is essential to design a robust and optimal regulator that is both accurate and responsive to maintain the system parameters within their nominal ranges. However, with the integration of clean energy and intermittent generation quality caused by climate change, generating fluctuations in system frequency, coordinated AGC-PMS control with hybrid storage systems is required to improve the quality and stability of power systems. A hybrid energy storage system (HESS) can improve frequency and voltage control by balancing supply and demand, stabilizing the grid, and ensuring backup power. This article proposes a study approach integrating both AGC and a power management system (PMS) within an isolated Microgrid. Taking into account the integration of renewable energy sources (RESs), the proposed approach favors the use of an HESS to reduce fluctuations induced by the integration of RESs, which are themselves affected by climate variations. The system studied includes a photovoltaic generator and wind farm. A hybrid energy storage system was installed to ensure power management and control. It consists of redox flow batteries (RFBs), superconducting magnetic energy storage (SMES), electric vehicles (EVs), and fuel cells (FCs). The coordinated AGC-PMS strategy was tested across different case studies. The results obtained show good performance and demonstrate the validity and effectiveness of the proposed method.

5.9. Deep Learning for Cybersecurity Threat Detection in Industrial Process Control and Monitoring Systems

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The increasing digital integration of Industrial Control Systems (ICSs), including Supervisory Control and Data Acquisition (SCADA) and Distributed Control Systems (DCSs), has brought both operational efficiencies and greater exposure to cyber threats. Traditional cybersecurity approaches, such as signature- and rule-based Intrusion Detection Systems (IDSs), often fail to detect novel and stealthy attacks, posing significant risks to critical infrastructure. This paper presents a deep learning-based threat detection framework tailored for ICS environments, leveraging sensor data, actuator signals, and network communication logs. The framework incorporates advanced neural architectures, including Convolutional Neural Networks (CNNs), Long Short-Term Memory (LSTM) networks, and Transformer models to capture complex temporal and spatial patterns indicative of malicious activity. These models were trained and evaluated using the publicly available

HAI security dataset. The results demonstrate high effectiveness across all models, with the Transformer achieving the highest accuracy (92%), followed by the CNN (91%) and LSTM (90%). Precision scores were 93% for LSTM, 92% for CNN, and 91% for Transformer; recall was 92% for Transformer, 91% for CNN, and 90% for LSTM. All models yielded an F1-score of 91%, reflecting a strong balance between precision and recall. While each architecture showed strengths, the Transformer exhibited superior generalization. The study also addresses key challenges such as data imbalance, overfitting, explainability, and deployment constraints. Solutions such as hybrid modeling, federated learning, and digital twin integration are discussed to enhance resilience and scalability. The proposed approach demonstrates that deep learning can significantly strengthen real-time cybersecurity monitoring in ICS, offering a robust defense against evolving threats.

5.10. Development of a Temperature Regulation System for Solar Dryers Based on Artificial Neural Network-Driven Intelligent Control

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Solar dryers are recognized as sustainable and energy-efficient technologies for dehydrating agricultural products under environmentally friendly conditions. These systems utilize solar radiation as a renewable energy source to reduce the moisture content of produce while preserving its nutritional and microbiological quality. However, the performance of solar dryers is significantly affected by environmental variables such as ambient temperature, solar irradiance, and airflow rate, which fluctuate dynamically during the drying process. Conventional control strategies, such as Proportional–Integral (PI) controllers, often exhibit limitations in such nonlinear and time-variant systems due to their slower response and limited adaptability.

This study proposes an intelligent control approach based on Artificial Neural Networks (ANNs) to enhance the accuracy and responsiveness of temperature regulation within a solar drying chamber. A mathematical model of the drying process was developed and implemented using MATLAB R2014a and the Simulink simulation environment. The ANN-based predictive controller was benchmarked against a traditional PI controller through a series of comparative simulations. The results indicated that the ANN-based system achieved a settling time of 160 s, representing a 36% improvement over the 250-s response time observed with the PI controller. Moreover, the ANN controller maintained temperature stability within ± 1.2 °C, demonstrating superior precision and robustness.

The findings suggest that neural network-based intelligent regulation significantly improves the dynamic performance of solar drying systems, enabling the real-time optimization of drying conditions. This method holds considerable promise for automating and industrializing solar drying technologies, with potential benefits in energy savings and product quality enhancement.

5.11. Development of an ANN-Based Predictive Model for Intelligent Control of Water Hardness and TDS in Industrial Wastewater Treatment Using Ion-Exchange Resins

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Abstract. Water scarcity and environmental pollution remain among the most pressing global challenges of the 21st century, particularly in industrial regions. This study proposes an artificial neural network (ANN)-based predictive model for the intelligent control of water hardness (H) and total dissolved solids (TDS) mass concentration in the industrial wastewater treatment process using ion-exchange resins. Experimental data obtained from a pilot-scale purification system treating wastewater from the Kungrad Soda Plant in Uzbekistan were used to train and validate the model. The ANN was developed in MATLAB using a feedforward backpropagation algorithm, with H (in milligrams of calcium carbonate per litre, mg/L) and TDS (in mg/L) as input quantities and the servo valve opening degree (*SerK*) as the output quantity. The predictive model was trained on 80 experimental datasets and achieved high accuracy, with a mean squared error (MSE) of 9.72×10^{-4} and a regression coefficient $R = 0.987$, indicating a strong correlation between predicted and measured values. The trained ANN accurately modelled the nonlinear interdependence between influent water quality parameters and process control actions. For example, at input values of H = 2.0 mg/L and TDS = 20.0 mg/L, the model predicted a valve opening degree of 12.5%, which closely matched the empirical value. Similarly, when H = 3.43 mg/L and TDS = 35.5 mg/L, the model correctly predicted a minimised valve opening of 4.16%, confirming its predictive reliability across a broad operational range. These results demonstrate that the proposed ANN-based model can serve as an effective and reliable tool for real-time control and optimisation of wastewater treatment processes. Its ability to generalise from experimental data makes it particularly well-suited for dynamic and uncertain industrial environments, supporting smarter, data-driven decision-making in water resource management.

5.12. Development of an Early Warning Indicator Matrix (EWIM) for Kick Detection Using the DS-5000 Scientific Drilling Simulator

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Kick events during drilling operations represent critical safety risks, often escalating into blowouts if not detected and controlled promptly. Conventional detection relies heavily on isolated parameter alarms and manual interpretation, which may result in delayed responses. This study proposes the development of a real-time Early Warning Indicator Matrix (EWIM), a decision-support tool that integrates multiple real-time drilling parameters into a unified risk visualization model.

The EWIM is developed using simulation data generated from the DS-5000 Scientific Drilling Simulator, a high-fidelity tool replicating realistic drilling environments. The matrix integrates field-observable parameters such as flow in/out differential, pit gain/loss, standpipe pressure, rate of penetration, return flow percentage, hook load, and mud weight changes. These indicators are processed through a traffic-light threshold model (green, yellow, or red) to yield dynamic risk scores for kick onset.

A series of controlled kick simulations were executed to construct and calibrate the EWIM. Post-simulation analysis involving bottom-hole pressure and influx volume validates the matrix accuracy and sensitivity. Preliminary results demonstrate the EWIM's ability to provide earlier, more holistic warnings compared to traditional single-parameter monitoring.

This approach enhances both training outcomes and operational monitoring by offering a scalable, field-applicable framework for early kick detection. The proposed EWIM methodology makes a significant contribution to real-time process control and proactive safety in drilling operations.

5.13. Digital Twin Support to Raise Sustainability in Assembly Systems

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This contribution presents an extended approach to utilising digital twin (DT) technology to improve sustainability and operational efficiency in assembly systems. Based on the principles of Industry 4.0, the study examines how real-time virtual replicas of manufacturing processes can drive material optimisation, in-line quality assurance and waste minimisation. In the study, two DTs were developed for an actual circular pallet assembly line consisting of three workstations. The first represents the existing assembly process with one control operation at the end of the assembly process, while the second DT includes an improved process with control operations after each workstation. To demonstrate the suitability of the improvements, various 'what-if' scenarios can be run, using the results obtained to show that quality control after each workstation not only increases system efficiency, but also significantly reduces raw material consumption and waste. The results show a reduction in raw material consumption of 8–10%, a reduction in waste generation of 18–23% and consequently energy savings of up to 10% compared to the baseline process. In both cases, the DT framework enables rapid scenario analysis and parameter tuning, thus supporting flexible decision-making while complying with the defined sustainability KPIs. The findings confirm the effectiveness of the described approach in different assembly environments, especially those with high material waste, and demonstrate its applicability to other types of discrete manufacturing. The presented approach can also be adapted for continuous production processes in other industries. Overall, the study provides empirical evidence that monitoring and simulation using the digital twin can deliver measurable environmental and operational benefits and positions DTs as strategic tools for embedding sustainability into industrial operations.

5.14. Electrified Pressure Swing Distillation: A Systems-Based Sustainability Assessment

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The decarbonization of energy-intensive separation processes is critical for achieving net-zero goals in the chemical industry. While widely used for separating azeotropic and close-boiling mixtures, pressure swing distillation (PSD) remains highly energy intensive due to significant thermal demands. This study explores the integration of electrification and hybrid heat pump-assisted systems into PSD as a pathway to enhanced sustainability. This work presents a comprehensive systems-based assessment of electrified distillation designs, with a specific focus on tetrahydrofuran–water separation as a case study.

Using Aspen Plus and Aspen Plus Dynamics for steady-state and dynamic simulations, coupled with MATLAB-based multi-criteria optimization, we evaluated key performance indicators including thermal and exergy efficiencies, CO_2 emissions reduction potential, and controllability metrics. The electrified configurations employed electric reboilers and heat pumps as partial or full substitutes for conventional steam heating.

The results show that hybrid electrified systems can reduce primary energy demand by up to 28%, while improving exergy efficiency by 22% compared to conventional setups. Dynamic controllability analysis using the Morari Resiliency Index (MRI) and Condition Number (CN) confirmed enhanced stability and responsiveness under variable electricity input scenarios. Additionally, GHG emissions were reduced by 35–45%, depending on the electricity source mix.

This study demonstrates the potential of electrification to transform PSD systems from rigid, energy-intensive operations into flexible and sustainable processes. The findings support a shift toward integrated, systems-driven design strategies in chemical separation, aligning with broader goals in process electrification, circularity, and net-zero manufacturing. This approach can serve as a blueprint for retrofitting traditional separation systems with next-generation, low-emission technologies.

5.15. Embedding Environmental Intelligence into Digital Twins for Resource-Aware Process Control in Computer Networks

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Digital infrastructure contributes significantly to global electricity consumption, with data centres, high-speed communication networks, and edge devices operating continuously to meet growing computing demands. The infrastructure is evaluated based on performance characteristics such as throughput, latency, and fault tolerance. This study proposes a novel framework integrating environmental intelligence into digital twins to enable resource-aware process control in digital infrastructure. Factors including power usage, temperature, and e-waste generation are incorporated as key components. The digital twin model uses the energy profiles of routers, switches, and computing nodes across time and usage conditions, generating real-time data to predict variations and impacts. A multi-objective optimisation engine was developed using a weighted-sum approach to balance sustainability and performance objectives, with constraints on SLA adherence and hardware availability. The objective function optimises performance and energy consumption while maintaining network performance. We designed a proof-of-concept framework that acts like a cloud-edge network. The results showed that applying the modelling resulted in a 12.6% reduction in energy consumption and a 9.8% increase in performance under typical load scenarios. The system dynamically rerouted non-critical traffic during peak grid emissions, activated low-power modes during idle periods, and recommended infrastructure upgrades based on thermal hotspot forecasts and energy impact assessments. The proposed framework demonstrates how digital twins can align operational efficiency with sustainability by embedding intelligence into real-time control mechanisms. This approach supports the broader vision of intelligent and responsible infrastructure management for next-generation computing systems.

5.16. Evaluation of Project Workflow Control Strategies in Complex Organizations Using Agent-Based Simulation

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Cross-functional organizational projects are frequently challenged by executional uncertainty, complex interdepartmental dependencies, and constrained availability of role-specific human resources. This study presents a discrete-event, agent-based simulation framework designed to assess the effectiveness of three workflow control strategies—Static, Reactive, and Predictive—in managing task execution within resource-limited organizational environments. The simulation model emulates a structured procurement process comprising ten interdependent tasks executed by five functional roles: Engineering, Procurement, Finance, Legal, and Compliance. Each task is characterized by variable execution durations, precedence constraints, and department-specific resource requirements. Agents represent staff roles with finite availability, and tasks are processed in a non-preemptive, first-come-first-served manner. Control strategies are implemented as dynamic scheduling policies: the Static strategy follows a predetermined execution sequence; the Reactive strategy adapts in response to observed task delays or resource conflicts; and the Predictive strategy utilizes short-term historical performance data to forecast task durations and proactively adjust the schedule. The experimental design spans multiple configurations, varying control strategy type, task duration variability (low, medium, high), resource availability (full, moderate, limited), and project load (single vs. concurrent execution). Each configuration is simulated 100 times using Monte Carlo techniques to capture performance distributions. Key performance indicators include total project duration, average task delay, agent utilization rates, and rescheduling frequency. Simulation results demonstrate that the Predictive control strategy consistently outperforms its counterparts, particularly in high-variability, low-resource scenarios. It achieves this by anticipating future delays and smoothing resource demand, thereby minimizing downstream bottlenecks and task queue congestion. Analysis further reveals that highly central, resource-constrained roles—most notably in Finance and Legal—are primary contributors to systemic delay propagation. The proposed simulation framework offers an extensible methodology for analyzing general workflow processes in organizational systems and provides data-driven insights for optimizing project executions.

5.17. Fault Detection and Diagnosis in Electric Drive Systems

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This article addresses diagnosis and fault detection in electric drives, particularly for an asynchronous motor coupled to an inverter. The objective is to ensure service continuity and fault tolerance, both of which are essential in industrial applications. Electric machines are a fundamental component of all industrial operations. They play a critical role across various sectors due to their robustness, cost-effectiveness, relative simplicity, and ease of maintenance. The faults under investigation may affect the motor itself, the power converter, the mechanical components, or the sensors. The system operates at variable speed and is controlled using field-oriented vector control, along with speed regulation. Based on fault characterization results, obtained either from simulations or experimental measurements, two diagnostic approaches are proposed:

Signal Processing Approach: To address the challenges associated with variable speed operation, constant position increment sampling is applied. Analytical Redundancy Ap-

proach: Dedicated observers are designed and experimentally validated for effective fault diagnosis and detection.

Finally, based on the developed tools, strategies are proposed to implement a comprehensive electric drive monitoring system. This system is designed to continuously assess the health status of key components and to detect faults and malfunctions within the industrial process. As a result, this work contributes to enhancing system reliability, minimizing downtime, and enabling predictive maintenance in industrial environments.

5.18. Fuzzy-Logic-Based Intelligent Control of a Cabinet Solar Dryer for Plantago Major Leaves Under Real Climatic Conditions in Tashkent

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This study presents the modeling, simulation, and experimental validation of a fuzzy-logic-based intelligent control system applied to a cabinet-type solar dryer for drying Plantago major leaves under real climatic conditions in Tashkent (Uzbekistan) during the summer season. Traditional on/off and PID controllers often fail to maintain optimal drying conditions due to nonlinearities and fluctuations in solar radiation and ambient temperature. To address these limitations, a fuzzy inference system (FIS) was developed in MATLAB/Simulink using two input variables—internal air temperature and relative humidity—and one output variable—fan speed. The fuzzy system employed seven linguistic rules with triangular membership functions, allowing for smooth and adaptive real-time control. The experimental setup included a cabinet solar dryer loaded with 1,5 kg of Plantago leaves. During field trials, the solar irradiance ranged from 650 to 900 W/m^2 and ambient temperatures from 32 °C to 42 °C. The fuzzy controller's performance was benchmarked against a conventional PID controller. The results showed that the fuzzy system reduced the total drying time by 22%, improved energy efficiency by 18%, and ensured a better moisture uniformity ($\pm$4%) across trays. Moreover, the post-drying phytochemical analysis confirmed better preservation of heat-sensitive bioactive compounds. The fuzzy controller maintained the drying air temperature within the optimal 45–50 °C range, even under fluctuating external conditions. This study demonstrates that fuzzy logic provides an effective solution for adaptive solar drying in hot continental climates. Future work will focus on integrating IoT-based remote monitoring and hybrid control optimization to enhance automation and scalability.

5.19. Hybrid Quantum-Fuzzy Control for Intelligent Steam Heating Management in Thermal Power Plants

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In recent years, intelligent control of complex thermodynamic systems has gained increasing attention due to global demands for higher energy efficiency and reduced environmental impact in industrial settings. This study explores the integration of quantum control methodologies—grounded in established principles of quantum mechanics—into the automation of thermal processes in power plant operations. Specifically, it investigates a hybrid quantum-fuzzy control system for managing steam heating processes, a critical subsystem in thermal power generation. Unlike conventional control strategies that often struggle with nonlinearity, time delays, and parameter uncertainty, the proposed method incorporates quantum-inspired optimization algorithms to enhance adaptability and robustness. The quantum component, based on recognized models of coherent control and

quantum interference, is utilized to refine the inference mechanisms within the fuzzy logic framework, allowing more precise handling of state transitions in multivariable environments. A simulation model was constructed using validated physical parameters of a pilot-scale steam heating unit, and the methodology was tested against baseline scenarios with conventional PID control. Experimental protocols and statistical analysis confirmed measurable improvements: up to 25% reduction in fuel usage under specific operational conditions, with an average of 1 to 2% improvement in energy efficiency. The results suggest that quantum-enhanced intelligent control offers a feasible pathway for bridging the gap between quantum theoretical models and macroscopic thermal systems, contributing to the development of more energy-resilient industrial automation solutions.

5.20. Mathematical Modelling of the Kinetics of Biomethanol Production on a Fibrous Cu/Zn/Al/Zr Catalyst from Biomass-Derived Syngas

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The accelerated growth of the global economy has contributed to the shift towards sustainable energy sources, amplifying the need for biomethanol production from biomass-derived syngas. This study evaluated an extensive kinetic model incorporating equilibrium restrictions for biomentanol synthesis utilizing a fibrous Cu/Zn/Al/Zr catalyst. A modified Langmuir–Hinshelwood–Hougen–Watson (LHHW) model was employed to better capture the equilibrium effects of CO hydrogenation, CO_2 hydrogenation, and reverse water gas shift (RWGS) for precise predictions. Parameters evaluated included temperature (200–300 °C), pressure (50–100 bar), H_2/CO ratio (1.5–2.5), and H_2/CO_2 (2.5–3.5) molar feed and space velocity (100–1000 h^{-1}). LHHW rate constants were calculated from pilot scale experimental data, and the model bioethanol yield was compared against ground truth values, yielding a deviation of 7.23%. The LHHW was solved with the ODE15s solver in MATLAB to address the stiff equations generated by the LHHW model. Sensitivity analysis evaluated by the finite difference technique assessesed the uncertainty of biomethanol yield, highlighting that pressure had the most influence. From this, an 11.70% yield increase was seen when pressure was raised from 65 to 75 bar. ChemCAD8 was employed for process flowsheeting, enabling quantification of the biomethanol yield, and analyzed with the coefficient of determination (R^2), root mean squared error (RMSE), mean squared error (MSE), and mean absolute error (MAE). The model attained an R^2 of 0.9756, an MSE of 0.2453, an RMSE of 0.4953, and an MAE of 0.035. A plug-flow reactor simulation reached 0.402 kg methanol per kg biomass with 87.3% CO_2 conversion, compared to experimental values of 0.379 kg/kg and 81.4%. The simulation carried a $\pm$4.23% uncertainty at 95% confidence. These results were generated at optimal points spanning 246 °C, 78 bar, 379 h^{-1}, $H_2/CO = 2.3$, and $H_2/CO_2 = 3$. The refined kinetic model accurately predicted biomethanol performance; however, for effective scale-up application, heat management of the catalyst should be practiced.

5.21. Measuring Air Pollution in Populated Areas Using Sensors Installed on Vehicles and Drones

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Residential heating is a major contributor to atmospheric pollution, especially in populated areas. Traditional methods for measuring emissions, such as chimney probes, are limited due to the need for prior owner consent, which can compromise the reliability of results—particularly when detecting the illegal burning of materials like plastic or waste oil. This study introduces a mobile air pollution monitoring system using compact sensor modules installed on vehicles and drones. These autonomous modules are equipped with gas, particulate matter, and environmental sensors, along with GPS tracking to record pollutant concentrations in real time and associate them with specific geographic locations. Field experiments conducted in Hungary and Uzbekistan demonstrated the system's effectiveness in detecting elevated pollutant levels in rural areas with solid-fuel heating and in urban zones affected by industrial activity and traffic. For instance, PM2.5 concentrations ranged from 15 $\mu g/m^3$ in forested areas to as high as 160 $\mu g/m^3$ in industrial zones, while CO_2 levels near chimneys exceeded background values by 15–25 ppm. Drone-based measurements enabled vertical profiling and direct analysis of emissions from individual chimneys, providing detailed spatial distribution data. The proposed mobile sensing approach allows for the accurate localization of pollution sources and the assessment of air quality variations within small-scale environments. This method overcomes limitations of stationary or pre-announced inspections and supports proactive environmental monitoring and enforcement.

5.22. Model Predictive Control of a Data-Driven Model of a Medium-Temperature Cold Storage System

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At temperatures higher than 5°C in the cooling chamber of refrigeration systems, bacteria multiply rapidly on fresh fishes, thereby leading to an increased risk of foodborne diseases. Maintaining the storage temperature within the recommended bounds of 0 °C and 5 °C is needed to maintain food safety and quality. This study presents model predictive control of a data-driven medium-temperature cold storage system using a subspace system identification technique. The identified linear model presents a holistic view of the whole system, with each subsystem cohesively linked together. The data-driven model was developed from synthetic data derived from a high-fidelity simulation benchmark model of a supermarket refrigeration system from Aalborg University, Denmark. The benchmark model consists of a medium-temperature closed display case, the suction manifold and the compressor rack. The data on the expansion valve, suction pressure, compressor capacity, heat transfer rate and ambient temperature were taken as inputs, while the data on the air and goods temperatures were taken as outputs based on expert knowlege. A linear model predictive controller was designed to control the temperature outputs of the identified linear model, and the outputs were compared with the proportional–integral dead band control used in the benchmark. Simulation results for 24 h show that the model predictive controller was able to achieve an air temperature and a goods temperature within the recommended temperature range of 0 °C and 5 °C that guarantees safe storage of fresh fishes. These results imply that a reduced-order model of a commercial refrigeration system

that is robust, reliable and stable can be developed and controlled to achieve the goal of food safety, thereby guaranteeing food security and reducing costs.

5.23. Modeling and Control of Nonlinear Fermentation Dynamics in Brewing Industry

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This paper presents a mathematical modeling and advanced control strategy for the beer fermentation process, which is characterized by nonlinear biochemical kinetics and time-dependent dynamics. A biokinetic model was developed to describe the relationship between yeast growth, sugar consumption, and ethanol formation. The system was represented as a cascade of several continuous stirred-tank reactors (CSTRs), and experimental data confirmed a fermentation cycle of approximately 10 days. During this period, biomass concentration reached 6.8 g/L and ethanol levels exceeded 42 mmol/L. Substrate concentration (S) declined from 120 to 5 g/L, demonstrating effective conversion. The model was linearized around an operating point and reformulated into a 12-state space system with input variables: temperature (set at 20–22 °C) and pH (maintained within 4.2–4.5). These inputs were controlled using fuzzy logic control (FLC) and model predictive control (MPC). Simulation results indicated that the FLC controller reduced temperature deviation to ± 0.3 °C and minimized pH fluctuation below ± 0.05. The MPC strategy improved substrate consumption efficiency by 8.5% and decreased fermentation time by 12 h under optimized input profiles. The combined FLC–MPC control scheme demonstrated superior robustness, smooth trajectory tracking, and adaptability to biological variability compared to traditional methods. The developed framework supports intelligent brewery automation and provides a scalable foundation for further integration of digital fermentation technologies.

5.24. Modelling of Open-Circuit Cooling System Chemical Emissions to River Water via Blowdown Water, and Their Impact on the Quality of Effluents Discharged

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Introduction: Open-circuit cooling systems (OCCS), integral to industrial processes, often release blowdown water containing high concentrations of treatment chemicals. If unmanaged, these discharges pose substantial risks to aquatic ecosystems and human health. This study addresses the environmental implications of chemical emissions from OCCS blowdown by developing a predictive model to estimate contaminant concentrations in receiving water bodies.

Methods: The research employs a computational model based on mass balance equations to simulate the dynamics of chemical emissions from blowdown water. It incorporates key operational variables, including flow rates, degradation rates, and volatilization characteristics. The model evaluates two chemical dosing strategies: continuous and fractional, and their resultant pollutant dispersal patterns in river systems. Validation was conducted using empirical data from sulfuric acid (H_2SO_4) applications at the nuclear power plant between 2015 and 2022.

Results: The model showed strong agreement with observed sulphate ion concentrations in the receiving water body, confirming its predictive reliability. Continuous dosing resulted in stable levels of pollutants, while fractional dosing caused temporary peaks that did not exceed regulatory values.

Conclusion: The modeling of blowdown water reveals significant implications for river water quality and highlights the urgent need for more effective wastewater management strategies within industrial contexts. Validation with measured SO_4^{2-} concentrations confirmed the model's accuracy, making it a valuable tool for guiding regulatory compliance and optimizing cooling water treatment practices.

5.25. Modelling of Wastewater-Based Epidemiology in the City of Johannesburg to Determine Phenoxymethylpenicillin and Its Derivatives Wastewater Treatment Systems

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Phenoxymethylpenicillin is a narrow-spectrum β-lactam antibiotic commonly used in South Africa. It is considered a pharmaceutical pollutant in municipal wastewater treatment plants (WWTPs), requiring wastewater-based epidemiology (WBE). Realistic simulation of phenoxymethylpenicillin degradation in wastewater treatment plants is limited by multifaceted microbial dynamics and fluctuating physicochemical conditions. This research examines pseudo-first-order degradation kinetics utilizing MATLAB calculations to estimate the distribution and transition pathways of phenoxymethylpenicillin in wastewater treatment plants in Johannesburg. Existing high-performance liquid chromatography–mass spectrometry (HPLC-MS) analytical data was used as modeling data, calibrated in line with critical parameters including sludge retention time (5–25 days), hydraulic retention times (4–12 h), influent concentration variability (0.1–10 μg/L), degradation constant k (0.05–0.2 h^{-1}), and operating temperature profiles (15–30 °C). Sensitivity analysis identified critical parameters influencing degradation, whereas model validation included the coefficient of determination (R^2) and mean squared error (MSE) to compare simulated outputs with measured concentrations. The established model confirmed that pseudo-first-order kinetics effectively characterizes the degradation curve, exhibiting performance metrics of R^2 at 0.9734 and an MSE of 0.675, which are within acceptable thresholds, aligning with similar β-lactam research. The validated model provides dependable predictions of phenoxymethylpenicillin, facilitating the amalgamation of chemical kinetics, simulation modeling, and environmental engineering techniques to combat pharmaceutical contamination in urban water systems.

5.26. Monitoring and Fault Diagnosis in Photovoltaic Systems for Enhanced Performance

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Like any industrial process, a photovoltaic (PV) system can be subject to various faults and anomalies during its operation, leading to a decrease in performance or even system shutdown. This thesis focuses on advanced diagnosis, as well as the detection and localization of faults in a PV installation, with the aim of reducing maintenance costs and optimizing productivity. Photovoltaic solar energy represents a promising alternative to the gradual depletion of fossil resources, due to its many advantages: cleanliness, renewability, silent operation, and low environmental impact. The presented work involves monitoring the behavior of photovoltaic cells under various climatic conditions. The modeling is based on equivalent electrical circuits, allowing for the analysis of the I-V and P-V characteristics of the generator. The simulation, carried out using MATLAB/Simulink, highlights the effect of variations in irradiance and temperature on the energy performance of the system.

In addition, a detailed study of typical faults affecting the various components (modules, cabling, junction boxes, converters, and inverters) is conducted, with each fault analyzed in terms of its potential impact on overall efficiency. Finally, monitoring and diagnostic methods are proposed, based on the real-time measurement of parameters and the calculation of derived quantities such as efficiency, energy losses, or the performance ratio. This work thus contributes to improving the reliability, efficiency, and maintenance of photovoltaic installations, from a sustainable development perspective and with the goal of optimal integration into the energy mix.

5.27. Optimal Power Management and Dispatching of Renewable Resources in a Prosumer-Centric Environment

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The transition toward sustainable energy systems has given rise to a new trend in the electrical power grid, where consumers actively participate in energy production and management—commonly referred to as prosumers. By simultaneously producing and consuming electricity, these prosumers reshape the electricity landscape by creating new complexities and possibilities for managing the energy distribution, especially with the increasing rate of renewable energy integration into the grid. This paper proposes a novel optimal economic dispatch and control method for smart power management and dispatching of renewable energy sources (RESs) in a prosumer-centric-environment-based residential microgrid. The proposed strategy integrates renewable energy sources, including solar and wind generation, within a decentralized microgrid architecture coordinated with energy storage devices. The prosumer microgrid includes a photovoltaic (PV) system, a wind turbine, a Hybrid Energy Storage System (HESS), and an Electrical Vehicle (EV), as well as electrical loads. The HESS includes Redox Flow Batteries (RFBs), Superconducting Magnetic Energy Storage (SMES), and Fuel Cells (FCs). By employing a Fuzzy-Logic-based Power Management System (PMS) optimized via the Particle Swarm Optimization (PSO) algorithm, the control method ensures efficient energy allocation and minimizes operational costs while maintaining grid-connected microgrid stability. Simulations of several market-based interaction scenarios between prosumers and the grid were conducted. The simulation results demonstrated the effectiveness of the proposed approach in achieving economic benefits while empowering end-users to take on a role in the energy ecosystem.

5.28. Optimal Storage System Managment to Enhance Dynamic Microgrid Frequency Control

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This paper deals with the design of an optimal storage management system to enhance microgrid frequency stability and control in the presence of Renewable Energy Sources (RESs) including a solar PV generator and wind farm. In a classical power system, a Load Frequency Control (LFC) loop is applied to cope with frequency deviations by acting on the selected conventional power generation unit such as thermal or nuclear power plants. On the other hand, in the case of small or islanded areas, this option is not applicable due to the lack of power generation units with such inertia. In this context, implementing a storage system seems to be a good solution to handle dynamic frequency deviation in microgrids, which is the main contribution of this paper. The main idea was to create a centralized multi-storage system that can support frequency control using a smart power

management strategy using nature-inspired optimization algorithms. A hybrid energy storage system was employed including an electrical vehicle, redox flow batteries, super conducting magnetic energy storage and fuel cells. Each storage unit was controlled using an optimal Fuzzy-PIDN controller. A recently developed optimization algorithm named Mountain Gazelle Optimizer (MGO) was used to find the best controller parameters, aiming to improve the storage units' control and management to support the microgrid frequency control in case of load disturbances or climatic changes. The proposed control strategy ensures efficient energy sharing and enhances dynamic microgrid stability. Several scenarios were performed to demonstrate the validity of the proposed method. Firstly, the proposed strategy was simulated in presence of static and dynamic load changes, and then the study was extended to study the impact of climatic changes on green power generation sources such as wind speed variation and solar shading to reduce the maximum frequency deviation and find a robust solution to avoid power outages and load shedding.

5.29. Optimized PID Control for Trajectory Tracking of an Unmanned Ground Vehicle in a Virtual Environment

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In well-mapped environments such as estate buildings, Unmanned Ground Vehicles (UGVs) play a crucial role in applications such as mail delivery, waste collection, and security surveillance. These vehicles operate autonomously or under remote human control. For autonomous UGVs, trajectory tracking controllers are essential for the wheels to accurately follow the desired path with minimal or no tracking error. The Proportional–Integral–Derivative (PID)-based control approach is one of the most widely adopted techniques for path tracking; however, its performance can degrade due to improper parameter tuning and external disturbances. Thus, this research aims to develop an optimized PID controller for trajectory tracking of a UGV in a virtual simulation environment, UGV3DSim. This was achieved by modeling and simulating a four-wheel UGV with front wheel steering control and rear wheel speed control in MATLAB/Simulink. The physical model of the UGV, comprising the chassis, top cover, and wheels, was designed using 3D modeling software and imported into the virtual environment. Three optimized PID controllers were developed using the Single Candidate Optimizer (SCO) algorithm, the Ali Baba and the Forty Thieves (AFT) algorithm, and the Walrus Optimizer (WO). These controllers were evaluated across various trajectory scenarios: linear and circular paths, go-to-goal navigation, and infinity-shaped trajectory tracking. The performance of the developed controllers shows that the WO-based controllers generated better trajectory tracking, had minimum overshoot, and settled faster in all three scenarios.

5.30. Prediction of Drying Efficiency in Cabinet Solar Dryers for Medicinal Plants Using Artificial Neural Networks

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This research presents a neural network-based predictive model to evaluate the operational performance of a cabinet-type solar dryer utilized for dehydrating *Plantago major* leaves under natural climatic conditions. While solar drying is known for its sustainability and energy efficiency, its performance is highly influenced by complex, nonlinear factors such as solar irradiance, internal chamber temperature, and ambient humidity. To overcome the constraints of conventional statistical modeling, a multilayer feedforward

artificial neural network (ANN) was constructed using MATLAB's Neural Network Toolbox. The architecture consisted of an input layer with three neurons, two hidden layers each containing ten neurons, and a single output neuron. Input parameters included solar radiation (W/m^2), drying chamber temperature (°C), and relative humidity (%), while the output was defined as drying efficiency, calculated from weight loss and initial/final moisture content. Experimental data were gathered during the summer season under varying irradiance levels (650–900 W/m^2) and ambient temperatures (30–42 °C), yielding 120 samples. The dataset was normalized and partitioned into training (70%), validation (15%), and testing (15%) subsets. The network was trained using the Levenberg–Marquardt optimization algorithm to minimize the mean squared error. The final model achieved a strong predictive correlation (R^2 = 0.97) and low error (MSE 0.0015), demonstrating a 22–25% improvement over traditional models. This methodology enables real-time monitoring and supports the integration of intelligent control systems in solar drying processes, enhancing both efficiency and consistency.

5.31. Robust Control Design for an Off-Board EV Charger Considering Grid Impedance Variation

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Grid impedance variation has the possibility of leading to voltage oscillation and control instability, which poses a serious problem to electric vehicle (EV) charger design. In response to this problem, this paper proposes a robust control approach that is capable of dealing with grid impedance variation and system uncertainties. The proposed dual-loop control strategy is composed of an outer-loop proportional–integral (PI) controller and an inner-loop robust state feedback controller with integral action. The benefits of control are maximized according to linear matrix inequality (LMI) techniques. This paper aims to address the effects of grid impedance variation by including the uncertainty model considering the potential varying parameters in the control design process. Additionally, the uncertainty model considers sixteen possible sets, which are described by variations in the four most important parameters: grid impedance, grid resistance, filter impedance, and filter resistance. Compared to PI control, this LMI-based robust control method provides significantly improved disturbance rejection, faster transient response, and greater resilience to parameter variations, ensuring a more reliable and efficient operation of the EV charger. This proposed single-stage AC/DC EV charger topology also offers higher efficiency, reduced component count, and lower cost compared to conventional double-stage designs, making it a more compact, reliable, and economically attractive solution for modern electric vehicle charging systems. The simulation results confirm that the designed control method maintains excellent charging performance under different grid impedance conditions with a unity power factor.

5.32. Trajectory Tracking Control of a Quadrotor: A Comparative Study of PSO- and FPA-Optimized PID Controllers

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Trajectory tracking control is a critical aspect of quadrotor performance, requiring high precision, stability, and responsiveness. This paper presents a comparative analysis of PID control optimization for quadrotor trajectory tracking using Particle Swarm Optimization

(PSO) and the Flower Pollination Algorithm (FPA). The study aims to evaluate the effectiveness of these metaheuristic algorithms for enhancing PID controller performance in terms of stability, precision, and response speed. The optimization process involves tuning the PID parameters using PSO and FPA to achieve optimal tracking performance. PSO, inspired by swarm intelligence, efficiently explores the search space to find optimal controller gains, whereas FPA, inspired by the pollination process in nature, provides a balance between exploration and exploitation. The optimized controllers are tested through simulations, where various trajectory scenarios are implemented to assess their performance. Simulation results indicate that both PSO and FPA significantly enhance the quadrotor's tracking capability compared to conventional PID tuning methods. However, a comparative analysis reveals key differences in their performance. While PSO demonstrates faster convergence and improved response speed, FPA exhibits superior stability and precision under dynamic conditions. The results provide valuable insights into the suitability of these algorithms for real-world quadrotor applications. This study highlights the potential of bio-inspired optimization techniques to refine PID control strategies, offering a robust approach for the improvement of quadrotor trajectory tracking. These findings contribute to the ongoing development of intelligent control methods for aerial robotics and autonomous flight systems.

6. Materials Manufacturing and Sustainable Packaging

6.1. Adaptive Facades and Smart Building Skins for Energy Efficiency: A Study for Materials Performance and Sustainable Design Processes

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The building aesthetic values known as facades which is a material treatment and known as one of the most challenging components of building. It also controls the indoor heating and cooling of building in the tropical climate areas and areas where temperature is below than 0 °C. In hot climate areas, during summer season temperature reaches about 40 °C–60 °C. A well designed exterior of building reduces heat absorption up to 50–60%. This research helps to improve thermal performance and reduce necessity to use artificial light in building during daytime. Natural air circulation in buildings play key role in thermal performance and reduces reliance on artificial cooling at daytime and at nighttime. Bricks and concrete blocks made with local materials like industrial waste are atmosphere friendly to reduce carbon footprints. With proper texture of bricks and concrete blocks almost reflects 50% of sunlight. The sustainability design of buildings is suitable for tropical regions. Simultaneously, four different parametric building models have been developed in Revit, two for hot and two for cold climates, incorporating other advanced passive design strategies such as optimized orientation, thermal mass integration, and adaptive insulation techniques helps us to analyses the results of better performance. The results of this study offer keen observation for professionals who want to enhance the performance of the sustainable structure design process.

6.2. Assessing the Environmental Footprint of Industrial Packaging

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More research is being conducted on the substantial environmental impacts of industrial packaging systems, including the depletion of material resources, greenhouse gas emissions, and the buildup of post-consumer waste. Growing worldwide supply chains and stricter sustainability regulations have raised the demand for environmentally friendly packaging options. This study critically examines the environmental impact of industrial packaging by integrating the most recent improvements in life cycle assessment (LCA) methodologies, ecological footprint (EF) assessments, material advancements, and circular economy models. The evaluation assesses the sustainability performance of both conventional and alternative packaging materials, including plastics, aluminum, corrugated cardboard, and polylactic acid (PLA). The findings demonstrate that, although renewable, corrugated cardboard still carries a notable environmental footprint, installing solar energy systems can reduce this footprint by more than 12%. When manufactured from renewable feedstocks and properly composted, PLA-based trays have potential effective environmental performance. There are still major challenges in spite of these developments. Ecological overshoot in industrial zones, where EF may exceed high biocapacity, waste disposal infrastructure shortcomings, and economic trade-offs are some of these. Transportation-related pollutants and the limited scalability of bio-based materials further impede widespread adoption. Studies suggest that employing sustainable industrial packaging could alter supply chain practices and reduce environmental impacts. To achieve this promise, cross-sector collaboration, standardized policy frameworks, and the integration of advanced environmental standards into packaging design and decision-making are required.

6.3. Assessment of the Service Life of Notched A36 Steel, Comparing Results from Experimental Methods with Predictions from Theoretical Damage Models

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A36 steel, also known as S235JR in Europe or ASTM A36 in the United States, is widely used in metal structures due to its good mechanical properties, durability, and weldability. However, one of the major challenges associated with its use lies in predicting service life, particularly in the face of fatigue and progressive damage. It is therefore essential for designers and operators to better anticipate the onset of defects and assess damage progression to ensure structural reliability and safety.

This work aims to estimate the service life of A36 steel through an approach combining experimental tests and theoretical modeling. Fatigue tests were conducted on notched specimens, followed by static tensile tests to measure the reduction in residual ultimate stress. The experimental results allowed us to plot the Wöhler curve (S-N) and determine the constants associated with the Erisman damage law. Subsequently, the Mesmacque law

was used to model damage evolution as a function of the fraction of life consumed, taking into account the loading sequence effect.

A comparison between the experimental results and the predictions provided by the analytical models was performed to assess their accuracy and their ability to represent the actual behavior of the material. This study identifies the most appropriate approaches to improve preventive maintenance strategies for A36 steel structures.

6.4. Biodegradable Smart Film Using Jackfruit (Artocarpus heterophyllus) Seed Starch and Beetroot (Beta vulgaris) Extract as a Freshness Indicator

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Food safety, quality deterioration and postharvest losses are growing issues and smart packaging has emerged as a critical solution to address these challenges. The global smart packaging market is currently valued at USD 24.28 billion and is projected to grow to USD 34.35 billion by 2030 with a compound annual growth rate (CAGR) of 7.12%. This study aimed to develop a biofilm based on jackfruit seed starch (JSS) incorporated with beetroot extract (BE) as a freshness indicator. Jackfruit seed starch was selected as the primary polymer matrix due to its high amylose content that enhances film-forming ability and structural integrity. Beetroot, which is rich in natural betalain color pigment, contributes to pH sensitivity. Four formulations of films were developed by the casting technique: Control without BE, F1 (10 mL BE), F2 (7 mL BE), and F3 (4 mL BE). The F2 formulation had a lower water activity value, moisture content value, and water vapor transmission rate, constituting (0.627 ± 0.003), ($10.596 \pm 0.106\%$), and ($11.636 \pm 0.082\%$), respectively, compared to F1, F3 and C. The lowest water solubility ($33.33 \pm 0.00\%$) was also shown by F2, compared to F1 and F3 films. Among all formulations, F2 had the highest hardness of 422.40 g. Thus, F2 showed more excellent physical and mechanical properties than F1 and F3. The F1 formulation exhibited the highest biodegradability ($94.837 \pm 0.552\%$), followed by C ($91.513 \pm 0.189\%$), F2 ($92.0033 \pm 0.1150\%$), and F3 ($88.050 \pm 0.437\%$). The pH sensitivity of the extract and film was confirmed using standard buffer solutions from pH 1 to 13. F1 showed reddish purple at (pH 1), red at (pH 6), and brownish yellow at (pH 13). Therefore, F1 had more pH sensitivity. Consequently, the developed biofilm serves as an eco-friendly, smart film for meat packaging, sustainable waste valorization and plastic reduction initiatives.

6.5. Biodegradable Packaging Materials in Clinical Nutrition: Bridging Health and Process Sustainability

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The healthcare sector, particularly hospital nutrition services, generates significant amounts of packaging waste, largely composed of non-biodegradable plastics. In light of increasing global focus on sustainable materials and environmentally responsible processes, this abstract explores the potential for integrating biodegradable packaging materials within clinical nutrition systems. Drawing from hospital-based dietetic practice, this contribution identifies key packaging challenges affecting both food safety and waste management and examines how material selection can improve sustainability without compromising patient care.

The use of food-safe biodegradable polymers, compostable trays, and recyclable materials in hospital food services is evaluated through a process-focused lens, emphasizing

material efficiency, safety standards, and the impact on clinical workflows. The importance of selecting materials that maintain nutritional integrity, reduce contamination risk, and align with environmental goals is discussed. Furthermore, the role of clinical nutritionists in advocating for sustainable packaging at the institutional level is highlighted, including their collaboration with procurement and supply chain teams. The importance of selecting packaging that maintains the nutritional quality of therapeutic diets while meeting institutional environmental goals is emphasized.

This contribution calls for greater interdisciplinary engagement between materials scientists, packaging engineers, and health professionals to develop and implement packaging innovations tailored to healthcare environments. By aligning sustainable materials development with the needs of clinical nutrition, we can advance both patient health and environmental stewardship.

6.6. Biogenic Silica from Agricultural Waste for Low-Cost Engineered Cordierite and Its Implication on Thermal Insulations

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The rapidly increasing global demand for high-performance thermal insulation materials necessitates a significant shift towards more sustainable and cost-effective solutions. This study unveils a novel and efficient pathway to synthesize engineered cordierite, a highly coveted magnesium aluminosilicate ceramic, by intelligently harnessing biogenic silica extracted directly from rice husk. Rice husk, an abundant agricultural by-product, represents a readily available and often underutilized resource. The methodology involved a precise precipitation method to successfully yield high-purity silica from rice husk ash. This extracted silica was then meticulously combined with commercial magnesium oxide (MgO) and aluminum oxide (Al_2O_3) through a solid-state reaction to synthesize the desired cordierite. This study systematically investigated the profound impact of various sintering temperatures, ranging from 850 °C to 1100 °C, on both the cordierite yield and its crucial physicochemical properties. Our experiments revealed that a sintering temperature of 1100 °C achieved a remarkable 66.5% cordierite yield. Beyond yield, the material processed at 1100 °C exhibited exceptional mechanical and thermal characteristics: a compressive strength of 65 kN/m^2, a flexural strength of 44 kN/m^2, a tensile strength of 17.5 kN/m^2, and a remarkably low thermal conductivity of just 3.2 W/m-K. These attributes not only match but, in some respects, surpass those of commercially available cordierite while simultaneously offering the dual advantages of enhanced resource sustainability and compelling economic viability. This groundbreaking research powerfully demonstrates the transformative potential of rice husk as a rich biogenic silica reservoir for fabricating advanced cordierite ceramics. It effectively paves the way for their widespread utilization in next-generation thermal insulation applications and makes a significant contribution to fostering a more sustainable and circular material economy.

6.7. Cassava Peel Starch–Alginate–Banana Peel Composite Edible Film for Food Packaging

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Introduction: Edible films from natural ingredients like cassava peels, alginate, and banana peels offer a promising alternative to conventional plastics in food packaging. The

present work explores the development of an edible film for packaging; analyzes the impact of varying concentrations of each component on film properties with regard to mechanical strength, water absorption, biodegradability, and antibacterial properties; and optimizes the composition.

Methodology: Cassava peel starch and banana peel paste are prepared by a worked-out procedure. Cassava peel paste is mixed with sodium alginate and heated to 80 °C. Banana peel paste, glycerol, and essential oil are added and stirred. The mixture in a petri dish is dried in a hot-air oven at 45 °C for 48 h. Biodegradability is assessed using the soil burial method. Solubility is determined by immersing the film in water and measuring weight loss. Mechanical properties are evaluated using a UTM. FTIR spectroscopy is used to identify functional groups in the edible films. Antibacterial tests are conducted using the Kirby Bauer method. The Box–Behnken factorial design is used to optimize the prepared edible films with respect to mechanical properties and solubility.

Results and Discussion: It was observed that the solubility of films increased with higher proportions of alginate and glycerol. Samples buried in soil showed rapid degradation within 1–2 days, which was an added advantage of the prepared films. From analysis of variance studies, the desirable combinations of various inputs for high solubility and good mechanical properties were identified. The optimum composition of the sample was determined as being 22 g cassava peel starch, 2 g sodium alginate, and 3 ml glycerol. The computed film properties were also validated experimentally.

Conclusions: Successful development of an edible film for packaging was accomplished and we characterized the various mechanical properties, the solubility of edible films, and the influence each ingredient exerted on these properties.

6.8. Design and Analysis of an Ultra-Wideband Reconfigurable Intelligent Surface (RIS) at 28 GHz for mmWave Applications

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This paper presents the design and performance analysis of a 1-bit reconfigurable intelligent surface (RIS) operating in the ultra-wideband (UWB) spectrum centered at 28 GHz, targeting next-generation mmWave communications. A novel elliptical patch unit cell integrated with a central horizontal slot is proposed. The structure is optimized for wideband reflection characteristics and includes a PIN diode for achieving dynamic phase switching. The unit cell is constructed on a Rogers RO5880 substrate with low dielectric loss to ensure minimal reflection loss and stable phase response over a wide frequency range.

Using full-wave electromagnetic simulations in CST Microwave Studio, we investigate the S-parameters, phase behavior, and reflection efficiency of the proposed structure across a bandwidth from 26 GHz to 32 GHz. The diode is modeled using a lumped RLC circuit, and both ON and OFF states are evaluated to confirm a near 180° phase shift essential for effective 1-bit RIS operation. In addition to unit cell characterization, we simulate RIS arrays of various sizes to examine the impact on radar cross-section (RCS) and beam shaping capabilities.

The results show that the RIS maintains good matching (S11 −10 dB), low reflection loss (1.5 dB), and consistent phase control, making it suitable for UWB beamforming applications. Future work will explore 2-bit RIS architectures for enhanced resolution and reconfigurability.

6.9. Development and Characterization of Biodegradable Packaging Material from Sugarcane Bagasse, Rice Straw, and Cogon Grass Leaves

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The rising global emphasis on sustainability has intensified the demand for eco-friendly packaging solutions. In response, biodegradable packaging materials derived from fibers sourced from agricultural byproducts and naturally abundant plants have emerged. The present study focused on the development of biodegradable packaging using fibers derived from sugarcane (*Saccharum officinarum*) bagasse (SB), rice (*Oryza sativa*) straw (RS), and cogon grass (*Imperata cylindrica*) leaf (CGL), an invasive weed. Using standardized alkali treatment for fiber extraction, three film formulations were prepared by blending SB, RS, and CGL fiber at ratios of 1:1:1 (P1), 1:2:1 (P2), and 1:3:2 (P3), and their biodegradability, water vapor transmission rate (WVTR), water uptake ratio (WUR), oil uptake ratio (OUR), water activity (WA), color metrics, and bonding structure were evaluated using FTIR analysis. These parameters were compared with those of commercially available biodegradable packaging to assess relative performance. Data were analyzed using one-way ANOVA, followed by Tukey's test, using MINITAB 19.0 software at a significance level of $p < 0.05$. Among the analyzed formulations, P3 demonstrated the most favorable performance across multiple parameters. It possessed significantly higher biodegradability (63.63 $\pm$ 9.09%; $p < 0.05$), supporting environmental compatibility and significantly favorable barrier properties, and the lowest WVTR (4.72 $\pm$ 0.59%), WUR (197.22 $\pm$ 9.62%), and OUR (138.9 $\pm$ 24.1%; $p < 0.05$), indicating enhanced resistance to moisture and oil penetration. It showed the lowest WA (0.65 $\pm$ 0.01; $p < 0.05$), potentially contributing to reduced microbial growth. Optically, P3 had the highest color difference (ΔE) compared to commercial biodegradable packaging (17.74 $\pm$ 0.10), with lighter appearance (L* = -15.74 ± 0.06) and a red hue (a* = 7.48 $\pm$ 0.13), enhancing its visual appeal. FTIR analysis further confirmed favorable performances of P3 with improved bonding structure. Hence, this study underscores the potential of utilizing agricultural residues and abundant natural fibers for developing biodegradable packaging that mitigates environmental impacts while contributing to the circular economy.

6.10. Development of 3D Printed Multifunctional Surgical Retractor Integrated with Suction and Irrigation Using 17-4Ph and 316L Stainless Steel

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This comprehensive study thoroughly discusses the creation and fabrication of an innovative multifunctional surgical retractor that is specifically intended for use in microsurgery. It places significant emphasis on the incorporation of advanced biocompatible materials that are appropriate for clinical applications in a surgical setting. The instrument is notably equipped with integrated suction and irrigation channels that are incorporated into a single cohesive structure, thereby enhancing its functionality. For its production, state-of-the-art metal additive manufacturing methods have been utilized, specifically employing 17-4PH and 316L stainless steel—both materials are highly recognized within the medical field for their superior biocompatibility and exceptional resistance to corrosion. The retractor has been meticulously crafted using a BLT-T400 printer, with designs generated in SolidWorks that aimed to fulfill both ergonomic and functional requirements

essential for intricate surgical procedures. To ensure its reliability, finite element analysis was performed in ANSYS, validating the structural integrity of the device under standard surgical stresses that it would encounter during operation. This study underscores the essential contribution of biocompatible materials in enhancing the design and production of safe, reliable multifunctional surgical instruments through the innovative techniques of additive manufacturing. The insights presented here contribute significantly to the ongoing advancements in surgical instrument technology, ensuring that such devices not only meet the functional demands of surgery but also adhere to the stringent safety and biocompatibility standards necessary for patient care.

6.11. Electrospun Nanofibers from PAN and Bio-Based Polymer Blend for Potential Biomedical Applications

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This work presents a preliminary investigation into the development of electrospun nanofibers composed of polyacrylonitrile (PAN) blended with a bio-based polymer. The aim is to explore the feasibility of combining a synthetic, process-stable polymer with a renewable, potentially biocompatible component to create hybrid nanofibers suitable for various biomedical applications. Various blend ratios were prepared and processed using electrospinning to evaluate general spinnability, fiber formation, and morphological characteristics. Scanning Electron Microscopy (SEM) was employed for surface analysis, showing continuous, bead-free fibers with morphology influenced by the composition and nature of the polymer blend. The integration of a bio-based polymer is expected to improve the material's biological performance while maintaining the structural benefits of PAN, offering a significant advancement in dual-functionality nanofibers. These nanofibrous materials could be relevant for future applications in fields such as wound care, filtration, or tissue-related systems, providing a promising avenue for further innovation. At this stage, the study focuses on the basic processing and structural characteristics, serving as a foundation for further investigation and development. Planned future work includes extended physicochemical characterization and comprehensive evaluation of application-specific properties, essential for practical deployment and usability. This approach supports the development of adaptable, functional nanomaterials based on sustainable components for future medical or bioengineering use, thus contributing to more sustainable and eco-friendly solutions in nanotechnology.

6.12. Enhancement of the Multiferroic Properties of Flexible PVDF-TrFE/$MnCoFe_2O_4$ Based Piezoelectric Nanogenerator for Energy Harvesting

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The growing demand for micro energy to power sensors, miniature electronics, and other microelectronic devices has drawn a lot of attention to flexible piezoelectric nano-

generators (PENG). The main issues being addressed at the moment are choosing the right materials and using straightforward production methods to provide better electrical performance in addition to good mechanical qualities and flexibility. Herein, we explored the role ferromagnetic manganese cobalt ferrite (MCF) in improving the energy harvesting potentiality of poly (vinylidene fluoride-Trifluoro ethylene P(VDF-TrFE) matrix. Six different piezoelectric composite films composed of (PVDF-TrFE) and various ferromagnetic manganese cobalt ferrite ($Mn_{0.5}Co_{0.5}Fe_2O_4$) content of (0, 1, 3, 5, 7, and 10%) were prepared via Dr. Blade cast heating coater technique accompanied by electric field poling. To investigate the optimum effect of the MCF nanoparticle content on the relative fraction of the electroactive β-phase and the crystallinity, X-ray diffraction (XRD) pattern and the Fourier transform infrared spectroscopy (FT-IR) were elucidated. Meanwhile, the relative fraction of the β-phase and crystallinity degree for 5% nanocomposite film are 89% and 48%, respectively. Finally, addition of MCF into the PVDF-TrFE matrix influences the piezoelectric properties drastically. Among the fabricated piezoelectric nanogenerators, the nanocomposite film with 5% MCF content reveals the maximum open circuit voltage of 30 V and the maximum current of 6.5 mA in the order of 2 compared to the neat polymer film. It was observed that our fabricated flexible piezoelectric nano-generator is a potential candidate for powering futuristic microelectronic devices.

6.13. Exploring Consumer Expectations and Environmental Impact in Sustainable Paper-Based Packaging: A Systematic Approach Using MCDA and TOPSIS

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Studies on consumer behavior and packaging trends indicate that sustainability now plays a key role in purchasing decisions. A qualitative study was conducted to investigate consumer expectations and opinions regarding sustainable paper-based packaging materials, with 60 participants involved in a two-stage focus group. In the first stage, participants shared their thoughts on existing packaging options and their expectations for sustainable materials. In the second stage, they assessed five paper-based prototype packages.

The findings revealed valuable insights into how consumers define sustainability, the factors influencing their decisions, and the impact of trends in other industries beyond FMCG. The study also explored life cycle assessment (LCA) and life cycle costing (LCC) to evaluate the environmental and financial impacts of these materials. An automatic Multi-Criteria Decision Analysis (MCDA) approach was employed to select the most suitable packaging material. The study embraced alternative and circular economy models, emphasizing the recovery of materials at the end of their lifecycle.

There is growing concern about packaging waste, particularly plastic packaging, and its negative environmental impact. This research highlights global concepts such as sustainable development, the circular economy, and social responsibility. The methodology used offers a combinatorial ranking system for each criterion based on a predefined weight distribution, utilizing the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method to rank packaging materials.

This approach provides a systematic, comprehensive framework for selecting packaging materials, applicable to any product.

6.14. Hydrophobic-to-Hydrophilic Transition of Polyethylene Surfaces via Salicylic Acid Grafting

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Polyethylene (PE) is one of the most widely used thermoplastics worldwide due to its excellent balance of cost, performance, and sustainability. However, its inherently hydrophobic and chemically inert surface limits its suitability for applications requiring adhesion, such as printing, painting, and lamination—particularly in flexible packaging. These limitations are especially pronounced with water-based paints, which are more environmentally friendly but less compatible with hydrophobic substrates. Plasma or corona treatments are commonly employed to improve surface wettability, but they often lack specificity, are difficult to control, and offer only temporary effects. In this study, we propose a surface functionalization method involving the grafting of salicylic acid (SA)—a polar, aromatic molecule—onto PE films via an aluminum-mediated alkylation approach that is compatible with continuous film processing systems.

Low-density PE films (15 × 15 cm; Dow 203) were surface-softened using infrared heating and then sequentially sprayed with a 155 mg $AlCl_3$ solution in 25 mL n-heptane and a 500 mg SA solution in 25 mL absolute ethanol using an airbrush (120° fan, 6 mL/min). Unreacted species were removed by ethanol sonication. The modified surfaces were characterized by Fourier Transform Infrared Spectroscopy (Nicolet 520) and optical microscopy (Andostar). Paintability was evaluated using red water-based paint.

Spectroscopic analysis confirmed the formation of aluminum salicylate complexes chemically anchored to the PE surface. Microscopy revealed uniform surface modification, and painting tests demonstrated a significant improvement in the wettability and adhesion of water-based paints. These results indicate that the proposed strategy effectively transforms the PE surface from hydrophobic to hydrophilic, enabling the use of eco-friendly paints.

6.15. Investigation of the Effects of Static Tensile Loading on the Mechanical Properties of an ABS

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Plastics are widely used in daily life due to their versatility, affordability, and ease of processing. Their extensive applications make it crucial to understand how they respond to mechanical stress, especially in structural or load-bearing contexts. This study investigates the behavior of ABS (Acrylonitrile Butadiene Styrene), a commonly used thermoplastic, under uniaxial tensile loading conditions. The objective is to assess how mechanical stress and accumulated damage influence its performance and durability.

Recent developments in fracture mechanics are applied to polymer structures, with a focus on accurate design and dimensioning to ensure long-term structural reliability. A detailed understanding of how polymers deform, yield, and fail under various loads—particularly in the presence of micro-defects—is essential for predicting their service life and identifying critical failure thresholds.

The research utilizes experimental tensile testing combined with analytical approaches such as non-linear regression and damage modeling. These methods enable precise characterization of the material's mechanical properties and identification of key indicators of degradation. By capturing the evolution of damage during loading, the study provides insight into the points at which maintenance or replacement becomes necessary.

The results contribute to improved design strategies for polymer-based components, ensuring safer and more efficient use in engineering applications; the findings also offer a foundation for future research into the development of more resilient polymer composites tailored for high-stress environments.

6.16. Materials Manufacturing and Packing Analysis: A Study for Sustainable Production of Composites Through Emerging Technologies for Infrastructure Management

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Compact and economical packing of materials are key to sustainable future production. Nowadays, technologies are emerging that make possible the detection of sustainable materials using imaging techniques. This study focuses on effective application of image-based analysis techniques in detecting material failures and thermal impacts for sustainable infrastructure management. Investigating on these techniques would increase the potential of thermal imaging in the building sector. Furthermore, as severe weather events are projected to increase, material resilience and energy efficiency are becoming two challenges that many countries face. The occurrence of different stresses on existing materials related to urban infrastructure are produced due to different environmental conditions. On the other hand, during cool, particular attention should be paid to ensure energy efficiency and change in performance. Image technology that is used in analysis of materials since decades to detect and visualize thermal imbalances through humidity or improper insulation. The results show that using image analysis process techniques can detect failures in materials 80% of the time applied, and temperature impact like overheating within ± 2 °C. These results show that imaging has great potential for the sustainable management of materials for infrastructures. This study will help in materials manufacturing and sustainable packaging. It can be studied with reference to energy efficency and this detection will help in efficent material application and mangement.

6.17. Mechanical Behavior and Failure Prediction of Corroded Central Wires in a Steel Lifting Cable: Experimental and Probabilistic Approach

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In this work, a stringent experimental procedure was developed to accelerate the corrosion of central wires extracted from 19 × 7 lifting cables so that it should take about a few tens of hours to reproduce several months of service-induced degradation. To an accuracy of 100 mm, the specimens were carefully cut, marked and immersed in a 30% sulfuric acid solution in laboratory maintaining conditions. At scheduled intervals (up to a 40-h total immersion time), selected samples were taken out of the solution, gently washed, and tested monotonically to failure to measure their residual ultimate force. The tests showed a pronounced, asymptotically approaching decrease in mechanical efficiency with increasing length of exposure. Further analysis of the force-versus-immersion data, using nonlinear regression tools, provided an explicit relationship between the normalized residual strength and the life fraction β, defined as the ratio of the immersion time to the total test duration. In this static environment, the damage curve is divided by using Erismann's damage law into three different damage regimes: a beginning degradation phase of slow, incipient damage; and intermediate stage of rapidly developing, critical degradation; and a final abrupt degradation zone. To further define the variability of material degradation, a probabilistic damage–reliability model built on a Weibull distribution linked the computed life fraction and the survival probability of any specific stress level. This hybrid methodology—integrating accelerated corrosion protocols with advanced statistical and analytical modelling—provides a strong predictive tool for determining the remaining life of the CWs and facilitates the introduction of focused condition-based maintenance policies.

6.18. Modified Atmosphere Packaging as a Tool for Extending the Shelf Life of Desi Gulab (Rosa damascena)

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Desi Gulab (*Rosa damascena*), a highly valued rose variety, suffers from a short post-harvest shelf life of typically 2–3 days. This study evaluated Modified Atmospheric Packaging (MAP) effectiveness in extending Desi Gulab flower shelf life and preserving quality. Freshly harvested flowers were packaged in Low-Density Polyethylene (LDPE), Polypropylene (PP), and Polyethylene Terephthalate (PET) films, alongside a non-packaged control.

The research involved respiration rate measurements, film property characterization, and gas balance modelling. Quality parameters, including petal colour (L*, a*, b* values), weight loss, internal package gas concentrations (O_2, CO_2, N_2), and textural properties (peak force, first peak force, stiffness), were monitored over 21 days. A trained sensory panel also evaluated the flowers, with subjective data analysed using a fuzzy logic approach, supported by ANOVA and Tukey's HSD tests.

The results showed that MAP significantly mitigated weight loss and preserved colour/textural characteristics versus the control, which lost over 60% initial weight by Day 10. PP packaging exhibited superior moisture retention, reducing weight loss to 7 g by Day 10 (from ∼10–11 g initial), and maintained the highest initial brightness (L* = 55.17 at Day 1). PET, with low permeability, maintained target gas concentrations consistently (O_2 at 1.8%, CO_2 at 9.08% by Day 21) and showed strong sustained colour retention (L* = 47.5 at Day 21). PET also exhibited the highest correlation (0.91) with fuzzy sensory quality scores, maintaining scores predominantly in the 6–8 range. LDPE provided intermediate results, while the control deteriorated rapidly. Fuzzy logic confirmed PP's stable preservation and PET's overall consistency. This study validates MAP as a promising strategy to extend Desi Gulab's shelf life, enhancing market potential and reducing post-harvest losses.

6.19. Predictive Modeling of Biodegradable Material Degradation Using Deep Learning with Improved Regulatory and Liability-Aware Approach

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There is a significant rise in the growth of the adoption of biodegradable materials across industries. Industries including packaging, healthcare, and consumer goods require accurate prediction of their degradation behavior to support environmental sustainability and to ensure regulatory compliance. Here, we propose a deep-learning-based framework that helps with the prediction of the decomposition rates and the associated environmental impact of biodegradable materials under diverse physicochemical conditions. We train the neural network on historical data on the material performance, environmental exposure, and microbiological interactions, and the model shows its generalization capacity for life cycle estimation. The model has also been associated with an attention layer that monitors the compliance with regulatory frameworks that govern material safety, quality, and consumer transparency. Standards and frameworks (including the ISO and ISI standards) are integrated into this layer to ensure adherence to product liability guidelines. Along with this, domain-specific regulations have also been used to fine-tune the predictive outputs, respecting the permissible limits on product labeling, shelf life, and environmental claims. This approach shows better predictive results and demonstrates compliance with the legal context, and the model evaluation ensures compliance and verification of the predictive results on the materials' life. Here, we explore a multidisciplinary approach that makes use of the learning abilities of the ML algorithms and align the model performance with ethical frameworks to ensure trust and monitoring, making an intelligent system for sustainable material design to improve sustainability and reusability following the regulations.

6.20. Process Control for Biowax Impregnation of Recyclable Packaging Papers with Enhanced Water and Oil Barrier Properties

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The industrial processing of innovative packaging papers with enhanced barrier properties has become ever more challenging due to the more stringent regulations on single-use-plastics (SUP), with extended applicability to coated papers. Although traditional packaging papers are based on renewable sources, they do not provide water and oil resistance and require the deposition of extruded polymer films or dispersion coatings that interfere with the paper recycling process. In this study, the impregnation of paper with biowax rendered barrier properties with enhanced water and oil contact angles. However, the close control of processing conditions on an industrial pilot line is critical in producing optimized product quality. Therefore, the effects of material grades and processing conditions were more closely monitored through design of experiments, allowing us to increase product performance and enhance flexibility for processing different material grades. In particular, variations in surface properties of the base paper, wax content, and control of processing temperatures were related to the oil and water contact angles. It was concluded that variations in base paper roughness should be considered for the efficient uptake and impregnation of wax, while contact angles are a good indication of the penetration of wax in the paper bulk. The increase in oil contact angles up to 60° further relates to the enhanced grease barrier properties of the impregnated paper. Although an improvement in water contact angles up to stable values of 116° was obtained, this is not predictive for a similar improvement in oil contact angles, while it perfectly relates to the wax coverage and surface roughness. The relations between performance in barrier properties and wax

coverage on both impregnated and non-impregnated paper sides are finally confirmed through a qualitative description by spectroscopic analysis.

6.21. Reliability and Damage Analysis of a Helical Strand Taken from a Steel Cable

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Wire ropes are essential components in lifting and handling systems, ensuring both the transmission of mechanical forces and operational safety. Their structure, composed of several strands wound helically around a central axis, provides the ropes with an optimal combination of flexibility, strength, and reliability. Among these components, the central helical strand plays a crucial role in the overall mechanical strength of the entire rope, absorbing a large portion of axial loads and contributing to stress distribution. However, during operation, this strand can suffer progressive damage due to wear, corrosion, or localized mechanical failures, which can lead to premature failure.

The main objective of this work is to study the damage mechanisms of this central strand and assess their impact on its mechanical performance. To this end, static tensile tests were conducted on new strands as well as on strands artificially damaged by shearing 1, 2, or 6 constituent wires, to simulate different levels of degradation. The experimental results made it possible to analyze force-displacement curves, determine mechanical characteristics (strength, stiffness, elongation), and observe failure modes.

Interpretation of these data highlights a clear correlation between the degree of initial damage and the reduction in the strand's structural reliability. This study thus provides new insights into the fatigue and failure behavior of damaged strands and provides a technical basis for implementing more effective preventive maintenance strategies in systems using wire ropes.

6.22. Risk Assessment of Lithium-Ion Battery Manufacturing and Recycling Using Fuzzy FMECA

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The increasing frequency and severity of lithium-ion battery fires have raised global concerns about their safety across the entire lifecycle—from production and use to recycling and disposal. Recycling facilities, in particular, face elevated process safety risks due to the complex handling of thermally unstable, flammable, and toxic materials. Incidents such as the 2024 recycling plant fire in Missouri and numerous battery-related aircraft fires reported by the Federal Aviation Administration emphasize the urgent need for systematic risk assessment approaches. This study applies Fuzzy Failure Mode Effects and Criticality Analysis (Fuzzy FMECA) to evaluate the risks associated with lithium-ion battery manufacturing and recycling processes. The method integrates expert judgment under uncertainty to prioritize failure modes related to thermal runaway during collection, flammable vapor

emissions, combustible dust generation, and hazardous chemical handling. A comprehensive fuzzy inference system is developed using 125 fuzzy rules, enabling risk prioritization through a Mamdani-type knowledge base. The defuzzification is carried out using the Center of Gravity method to convert fuzzy outputs into actionable risk rankings. By identifying and ranking the critical risks using fuzzy logic, the study provides a structured framework for improving process safety in battery manufacturing and recycling operations. The findings highlight the importance of proactive safety management as battery recycling becomes central to circular energy economies and environmental sustainability.

6.23. Sustainable Applications of Kenaf: From Biomaterials to Biochar-Based Biocomposites

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Kenaf (*Hibiscus cannabinus*), a fast-growing annual plant, is becoming acknowledged as a very adaptable and sustainable bioresource with diverse applications across several industries. Its production requires few inputs and produces substantial amounts of biomass, rendering it an ecologically sustainable and economically feasible raw resource. The growing interest in kenaf-based materials arises from their superior fibre quality, lignocellulosic structure, and versatility in various climatic environments.

These reviews examine recent advancements in the development of post-harvest machinery for kenaf and its versatile applications in the development of post-harvest processing in the kenaf fibre industry. A systematic literature review approach was employed to source peer-reviewed articles, patents, and technical reports from reputable scientific databases. The methodology involved thematic analysis and comparative evaluation of technological innovations, material performance metrics, and environmental impacts associated with kenaf-based products. Particular focus has been placed on the production techniques and material characterisation of kenaf-derived biochar and its incorporation into polymer matrices for the development of biocomposites. It also examined experimental studies and field data on kenaf's role in environmental remediation and its potential in carbon sequestration systems. This comprehensive analysis highlights the role of kenaf in advancing circular bioeconomy practices, emphasising its contributions to waste reduction, resource efficiency, and ecological sustainability.

This review provides a valuable foundation for future research and innovation in bio-based materials, underscoring kenaf's potential to drive sustainable development and resilience in material science and environmental engineering.

6.24. Smart Choices in Packaging Materials for a Sustainable Future

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Packaging waste has become a pressing environmental challenge, prompting industries to rethink their material choices and manufacturing strategies. This paper investigates how smart, informed decisions in selecting packaging materials can contribute meaningfully to sustainability goals. Drawing from the recent academic literature and industry reports, this study maps out the evolving landscape of sustainable packaging materials, including biodegradable bioplastics, recycled polymers, and plant-based composites. It explores how material selection affects not just product protection and shelf life but also environmental outcomes across the lifecycle, from raw material sourcing and energy use

in manufacturing to post-consumer waste management and circularity. Key trade-offs such as cost, availability, recyclability, and mechanical performance are critically examined. Special attention is given to emerging innovations like nanomaterials, edible films, and agricultural waste-derived packaging that hold promise but face barriers at scale. This paper also reflects on how policy, consumer preferences, and corporate sustainability commitments are reshaping packaging decisions in sectors like food, retail, and e-commerce. Rather than promoting a single "best" material, the analysis emphasizes context-sensitive choices grounded in lifecycle thinking and systems-level impact. By highlighting both the potential and the complexity of material decisions in sustainable packaging, this paper aims to guide researchers, designers, and industry stakeholders toward more responsible, future-focused approaches.

6.25. Spectroscopic Fingerprints of Few-Layer Graphene on PET: Toward Intelligent Food Packaging Systems

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This work explores the optical behavior of monolayer, bilayer, and trilayer graphene films synthesized via chemical vapor deposition (CVD) and transferred onto polyethylene terephthalate (PET) substrates, with the aim of assessing their suitability for integration into smart labels for food packaging. Graphene is selected for this application because it uniquely combines optical transparency, mechanical flexibility, and high electrical conductivity, enabling the realization of labels that are unobtrusive yet multifunctional. The increasing demand for sustainable and intelligent packaging solutions has driven interest in flexible and transparent materials capable of incorporating sensing or data-storage functions. Spectroscopic ellipsometry analysis demonstrates that the dielectric response of few-layer graphene on PET can be accurately modeled using two Lorentz oscillators. A strong absorption feature at 4.6 eV is attributed to the van Hove singularity in the graphene density of states. Unlike what has been observed for bilayer graphene on SiO_2/Si substrates, this peak does not show a red shift on PET, suggesting reduced exciton–substrate interactions and supporting turbostratic stacking. A second oscillator, centered around 4.0 eV, is assigned to π–π^* transitions typical of graphitic structures. The absence of significant spectral shifts highlights the substrate-dependent nature of excitonic features in graphene. These results provide a spectroscopic fingerprint for few-layer CVD graphene on flexible PET, which is essential for non-destructive quality control in industrial settings. Ultimately, this study contributes to the fundamental knowledge required to enable the development of transparent, flexible, and functional smart packaging technologies, where the ability to verify film quality via rapid, non-destructive inspection supports scalable production. The main advantages for packaging are the reliable integration of intelligent functions, the preservation of transparency and recyclability, and the possibility of adding sensing, traceability, and anti-counterfeiting capabilities without compromising the sustainability of PET-based food packaging.

7. Pharmaceutical Processing and Particle Processes

7.1. Ultraviolet (UV) Spectral Analysis of Acetylsalicylic Acid Present in Two Pharmaceuticals: Evaluation of the Linearity, Limit of Detection (LOD), and Limit of Quantitation (LOQ)

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The main aim of this research was to provide a complete and new ultraviolet (UV) analysis of acetylsalicylic acid, a non-steroidal drug, in acetonitrile as a solvent. It is a

low-cost method which is accurate, precise, easy to apply, and needs low reagent consumption. Using this method, we can precisely find the amount of pure acetylsalicylic acid from various pharmaceuticals in any specialized laboratories. A statistical validation process was successfully applied. The linearity of the method, system precision, method precision, method robustness, and method accuracy were studied and successfully determined. To evaluate the linearity of the method and exactly quantify pure acid acetylsalicylic acid from two pharmaceuticals by the proposed method, the absorption spectrum was plotted for a standard solution of 16.83 μg/mL in acetonitrile p.a. as a pure spectral solvent. The maximum absorption wavelength was found to be λ = 213 nm. The ultraviolet spectrophotometric method was linear over the entire concentration range between 1.20 μg/mL and 16.00 μg/mL, and the linear regression value was R^2 = 0.999. Acetylsalicylic acid pure calculated content was found to be 497.46 mg for the first pharmaceutical and 494.67 mg for the second product. These amounts were very close to the officially stated content of 500 mg, with very low average percentage deviations from this official content, (+) 0.51% and (+) 1.06%, respectively. The calculated average percentage deviations were below the maximum percentage limit (±5%) stated by the European and International Pharmacopoeias Rules. This method can be easily applied for the Technical Quality Control of pharmaceutical products containing acetylsalicylic acid as an active substance.

7.2. Advanced Modelling and Control Methods in Particulate Processes: A Multiscale Approach

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Introduction: Particulate processes are central to many scientific and industrial systems, from materials synthesis to astrophysical processes. A comprehensive understanding of particle dynamics—nucleation, growth, aggregation, and diffusion—is essential for process design, optimization, and control. This review integrates disparate modelling techniques and control strategies from fields like flame synthesis of nanoparticles, batch and continuous crystallization, and stellar evolution driven by particle motion.

Methodology: Embedded at the center of particulate modelling is the Population Balance Model (PBM) that follows particle size distributions via internal coordinates such as geometry, composition, and age. The model is designed to handle a range of complexities from basic spherical particles to full agglomerate structures. Numerical solutions, such as a method of moments, sectional methods, finite element analysis, and Monte Carlo simulations, are explained with applications to laminar as well as turbulent flows. On the control side, predictive control algorithms—specifically hybrid MPC systems—are presented for stabilizing and optimizing particulate processes. Complementary optical monitoring methods like turbidity and light scattering are reviewed, in addition to stochastic models based on Markov chain theory for the characterization of mesoscopic behaviors.

Results: Model predictive control in batch crystallization demonstrates tangible advantages, e.g., a 13.4% decrease in fines volume using linear vs. nonlinear cooling. Hybrid MPC systems improve the robustness and stability of continuous operations. In flame synthesis, different numerical solutions precisely reproduce particle growth and interaction behavior. In astrophysical applications, novel formulations of diffusion and radiative acceleration information improve stellar evolution models and better match observed phenomena like the lithium gap and chemical stratification in AmFm stars.

Conclusion: This summary emphasizes the interfacing of modeling, simulation, and control methodology required for the predictive analysis of particulate systems. Although rapid progress has been made, overlooked methods like Markov-based stochastic models offer a window of new innovation.

7.3. Advances in Pharmaceutical Processing and Particle Engineering of Garlic Extract-Based Formulations for Antifungal Therapy Against Candida tropicalis

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The increasing resistance of *Candida tropicalis* to conventional antifungal agents has necessitated the development of effective, biocompatible alternatives derived from natural sources. Garlic (*Allium sativum*), known for its potent antimicrobial activity, contains 33 bioactive sulfur compounds, some of them being allicin, ajoene, and diallyl sulfides, which exhibit strong antifungal effects. However, the clinical application of garlic extract in pharmaceutical formulations remains limited due to its chemical instability, rapid degradation, and limited bioavailability. This review highlights recent advancements in pharmaceutical processing and particle engineering approaches to enhance the stability, delivery, and therapeutic efficacy of garlic extract-based antifungal formulations. Emphasis is placed on innovative strategies such as nanoencapsulation, lyophilization, spray drying, and incorporation into biocompatible hydrogels for targeted delivery. Special attention is given to hydrogel-based systems due to their excellent mucoadhesive properties, ease of application, and sustained release potential, making them ideal for treating localized *Candida tropicalis* infections. This review also discusses formulation challenges and in vitro evaluation parameters, including minimum inhibitory concentration, minimum fungicidal concentration, and biofilm inhibition. By analyzing recent findings and technological trends, this review underscores the potential of garlic extract-based particle-engineered systems as sustainable and effective antifungal therapies. The scope of this review includes an in-depth evaluation of garlic extract-derived formulations, the application of particle processing technologies, and their translational potential in the design of next-generation antifungal delivery systems for managing *Candida tropicalis* infections.

7.4. Bioanalytical Methods and Bioavailability Study of Modified Oligosaccharides by Ionic Liquid as Potential Inhibitors Against SARS-CoV-2

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This work explores the bioanalytical methods and green procedures for the synthesis of small molecules–ionic liquids with N-glycans (GLc-O-SMol-HmILs), good applicable materials with bioactive properties as potential drugs anti-SARS-CoV-2. Methylimidazolium N-ethylamine has good applicability and is an active ionic liquid that acts with oligosaccharides very easily. Particularly, this ionic liquid is employed in the modification of oligosacharides obtained from human milk, lactoferrin (Hm), to produce a novel small molecule (Gl-SM-o-IL-HmLf). The advanced analytical techniques of UPLC/ESI-QTOF and MALDI-TOF mass spectrometry illustrated the identification and investigation of the modified small molecules–glycoproteins–ionic liquids (Glc-SM-IL-HmLf). Small molecules may be provided as significant potential drug candidates for inhibiting the selected targets of main protease (Mpro), RNA-dependent RNA polymerase (RdRp), Papain-like protease (PLpro) and trans-membrane protease serine 2 (TMPRSS2). The molecule had a slightly stronger interaction than remdesivir with Mpro and TMPRSS2. Similarly, the modified compound interacted with RdRp at a comparable level to the standard drug, which had slightly lower binding energy than remdesivir and its derivatives, and the novel small molecule-IL-HmLf has strong 10 H-bonding with the structures of four targets of main protease. The characterization and quantification of small molecules–ionic liquids linked to oligosaccharides were investigated by LCMS, GCMS, NMR, and UV-vis spectrometer. Molecular

docking disclosed the bio-activity of modifying glycoprotein–small Glc-IL-HmLf-molecules by elucidating their interactions with the inspected targets.

7.5. Design and Validation of a Sustainable and Comprehensive Analytical Method for Tracing Zolpidem in Water, Alcoholic, and Non-Alcoholic Beverages Using CPSME-LC-MS/MS for Confirmatory Analysis

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Introduction: Zolpidem, a widely prescribed non-benzodiazepine hypnotic from the imidazopyridine class, is used for the short-term treatment of insomnia due to its sedative and sleep-inducing properties. However, its rapid onset, strong sedative effects, and amnesic properties make it a substance of choice in drug-facilitated crimes (DFCs). Increasing reports of zolpidem misuse emphasize the need for novel detection methods in forensic toxicological investigations.

Method: To address the need for a robust and eco-friendly analytical approach, a miniaturized Vortex-Assisted Ultrasonication-based Cellulose Paper Sorptive extraction in combination with Liquid chromatography mass spectrometry/mass spectrometry (VAUS-CPSE-LC-MS/MS) method was developed and validated for the quantification of Zolpidem in different beverages, including alcoholic, non-alcoholic, and water samples. Isopropanol alcohol (IPA) was selected as the elution solvent and a "2 $\times$ 2" cm sized filter paper was selected for the experiment. To optimize the method, the statistical tool "Minitab Statistica 22.0" was employed where the Placket Burman Design and Central Composite Design were formed to identify influential parameters.

Results: Optimal conditions for the extraction were a vortex time of 90 s, ultrasonication time of 12.5 min, pH of 7.5, extraction time of 6 min, back-extraction solvent volume of 1.5 mL, and 6.5 pieces of filter paper. Chromatographic separation was achieved using UHPLC with a binary mobile phase of 0.1% formic acid in Milli-Q water (Solvent A) and 0.1% formic acid in acetonitrile (Solvent B). The calibration curve for target analytes was linear in the range of 1.325–1000 ng/mL with a regression coefficient (R^2) of 0.999. The method demonstrated excellent sensitivity with limits of detection (LODs) and limits of quantification (LOQs).

Conclusion: The developed VAUS-CPSE-LC-MS/MS method proved to be a sensitive, eco-friendly, and cost-effective approach for the detection and quantification of Zolpidem in complex beverage matrices. This method offers strong potential for application in forensic toxicology investigations involving drug-facilitated crimes, robberies, and suspicious deaths.

7.6. Integrating Artificial Intelligence and Process Analytical Technology in Pharmaceutical Development: Toward Pharma 4.0

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In the emerging Pharma 4.0 paradigm, pharmaceutical factories adopt Industry 4.0 digitalization (AI, IoT, etc.) to become "smart" manufacturing sites, improving throughput and enabling right-first-time processes. Integration of AI with Process Analytical Technology (PAT) provides a data-rich platform for real-time process understanding, consistent with Quality by Design (QbD) principles of building quality into manufacturing. For

example, spectroscopic PAT methods such as near-infrared (NIR) and Raman spectroscopy are widely employed to monitor blend uniformity, moisture, and crystallinity; AI-driven multivariate models can analyze these data to predict and control critical quality attributes on-the-fly, yielding improved consistency and reduced waste. This AI–PAT synergy has accelerated the development of complex products: for instance, COVID-19 mRNA vaccines were brought to market in months (instead of years) by leveraging machine learning and in-line PAT for rapid formulation and scale-up. Moreover, AI-enabled PAT enhances cost-efficiency and reduces labor needs in manufacturing. High automation can lessen the physical and cognitive demands on a limited workforce, and continuous PAT monitoring reduces the need for highly specialized operators, helping to address skill shortages. Process optimization with AI also allows smaller plant footprints and fewer production steps; these reductions in footprint and complexity lower capital investment and operating costs. Together, these benefits align with the Pharma 4.0 vision of efficient, QbD-driven development—enabling faster, more cost-effective drug development with built-in quality and lower resource use.

7.7. Integrating Pharmaceutical Processing into Hepatitis Virus Treatment Model: Optimizing Drug Release and Therapeutic Response

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Pharmaceutical processing plays a pivotal role in determining the therapeutic success of antiviral formulations, particularly in the management of hepatitis virus infections. Beyond the discovery of potent antiviral compounds, the formulation strategy and particle processes directly influence drug release behavior, bioavailability, and ultimately, clinical efficacy. In this study, a mathematical model is developed to explore the dynamic interaction between viral load, drug concentration, and immune response, while incorporating the influence of pharmaceutical processing parameters on the drug release profile. The model captures how drug formulation—including particle size, granulation, and controlled-release systems—shapes the release kinetics and enhances antiviral action. By simulating various release scenarios through a pharmaceutical processing-dependent function, this study offers valuable perspective into optimizing antiviral formulations for improved therapeutic outcomes.

Despite advances in drug discovery, the integration of pharmaceutical processing characteristics into predictive viral dynamic models remains underexplored. This research addresses this gap by bridging pharmaceutical engineering and biological modeling, offering a systematic framework to guide the design of more effective and patient-centric antiviral therapies. Furthermore, this approach enables quantitative evaluation of how formulation changes impact viral suppression over time, providing a critical perspective for optimizing treatment schedules. This holistic strategy could significantly enhance personalized medicine in antiviral treatment planning.

7.8. Modelling Rabies Transmission with Vaccination: Incorporating Pharmaceutical and Particle Processing for Pre-Exposure Prophylaxis Optimization

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Rabies remains a persistent zoonotic threat, particularly in regions where domestic dogs are the main source of human and animal infections. This mathematical model studies the dynamics of rabies transmission between canine populations (dog-to-dog) and from canines to humans (dog-to-human). The model incorporates susceptible, infected, and vaccinated compartments for both species, with pre-exposure vaccination as the key control strategy. Processes such as encapsulation, stability enhancement, and controlled release are modelled as parameters influencing vaccination rates in both dogs and humans. Specifically, the model introduces processing-dependent vaccination functions that reflect improved bioavailability, immunogenicity, and delivery efficiency due to advanced formulation techniques.

This interdisciplinary approach bridges mathematical epidemiology and pharmaceutical technology. Earlier rabies models focus on transmission and static vaccination, often ignoring vaccine formulation and delivery. Our current work fills this gap by incorporating pharmaceutical and particle engineering parameters into the vaccination terms of the model, thereby providing a more comprehensive framework for optimizing rabies control strategies in endemic regions.

Positivity and boundedness analyses confirm that all model variables remain biologically feasible and bounded over time. Stability analysis identifies thresholds for disease elimination or persistence. Numerical simulations show that enhancing pharmaceutical parameters increases vaccination impact, reducing peak infection prevalence in dogs from 18% to 5% and in humans from 4% to 0.8%, and shortening elimination time from 8 years to 3 years. Formulations with controlled release and improved stability maintain over 90% reduction in transmission for more than 5 years, compared to 60% over 3 years for conventional vaccines. This will ensure that the model's predictions are validated against realistic conditions and can effectively guide rabies control strategies.

7.9. Metabolic Profile Alterations in the Progression of ALD- and NAFLD-Induced Liver Cirrhosis

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This study aimed to characterize the metabolomic profile alterations in patients with liver cirrhosis resulting from alcoholic liver disease (ALD, n = 31) and non-alcoholic fatty liver disease (NAFLD, n = 8) compared to matched controls.

Materials and methods: We conducted a study of 39 cirrhotic patients and age-, gender-, and BMI-matched controls (n = 59) ($p > 0.05$ for all), which included pre-cirrhotic patients and healthy individuals. Metabolite level in the blood serum was determined by high-performance liquid chromatography and tandem mass spectrometry. In order to find out the relationship between certain metabolites and the presence of liver cirrhosis, a binary

logistic regression model was used to determine the odds ratio (OR) and 95% confidence interval (CI).

Results: This study employed targeted metabolomic profiling to analyze 96 serum metabolites in patients with NAFLD and ALD. The analysis of the obtained data allowed us to identify a spectrum of metabolites associated with liver cirrhosis in the outcome of ALD and NAFLD ($p < 0.05$) and multidirectional shifts in the concentrations of biologically active molecules. Fibrosis progression was associated with significant metabolite alterations: increased levels of kynurenine (OR 2.93 [1.56–5.51]), acetyl-carnitine (OR 1.08 [1.01–1.17]), epinephrine OR 26.5 [5.7–123.4], dimethylarginine OR 20.2 [2.5–164.8], and methionine OR 1.10 [1.05–1.16], along with decreased indole-3-carboxaldehyde OR 0.04 [0.003–0.45]), serotonin (OR 0.038 [0.01–0.15]), norepinephrine (OR 0.25 [0.11–0.56]), taurine (OR 0.98 [0.97–0.99]), and carnosine OR 0.55 [0.34–0.90]).

Conclusion: Comprehensive metabolomics studies remain challenging due to their high cost, leading most liver disease studies to focus on individual metabolite groups. In contrast, our targeted analysis of 96 serum metabolites provides a broad, multifactorial view of the metabolic alterations that occur in the context of ALD and NAFLD cirrhosis. The obtained data, which suggest enhanced oxidative stress, sympathetic activation, and mitochondrial dysfunction in progressive fibrosis, not only confirm previous findings but also uncover novel, previously invisible metabolic pathways and interactions.

7.10. NIR Spectral Analysis in Twin-Screw Melt Granulation: Effects of Binder Content, Screw Design, and Temperature

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Twin-screw melt granulation (TSMG) is a promising continuous process for producing solid pharmaceutical dosage forms. However, the application of Near-Infrared (NIR) spectroscopy as a Process Analytical Technology (PAT) tool in this context is still underexplored. This study evaluates the feasibility of using in-line NIR spectroscopy combined with chemometric modeling to monitor key formulation and process variables in TSMG, including binder content, screw configuration, and sample temperature. Experiments used lactose monohydrate and polyethylene glycol (PEG) 6000 as a model formulation. Blends were processed under four conditions, varying PEG content (10–20 wt%), screw design (kneading or conveying), and screw speed (100–175 rpm). Granules were analyzed in-line using NIR spectroscopy (1100–2300 nm), collecting 23 spectra per condition. Spectral data were preprocessed (SNV, derivatives) and analyzed via Principal Component Analysis (PCA) and Partial Least Squares (PLS) regression. These conditions reflected a design space supported by prior studies[1]. Additionally, ungranulated mixtures with 15 wt% PEG were conveyed through the granulator and their spectra were compared to granulated samples. Measurements were taken immediately after production and after cooling to ambient temperature to assess sample temperature effects. PLS models showed excellent predictive performance for PEG content, with R^2 values of 0.9998 (raw) and 0.9983 (SNV). PCA graphically discriminated between granulated and non-granulated samples, and between screw configurations, especially using raw and SNV data. Temperature effects on spectral profiles were evident: granules measured post-processing and at room temperature formed separated PCA clusters, especially with derivative preprocessing. These

findings confirm that NIR spectroscopy, combined with multivariate data analysis, enables non-destructive, real-time monitoring of formulation and process parameters in TSMG, supporting its integration as a robust PAT tool for enhancing control and product quality in pharmaceutical continuous manufacturing.

7.11. Nitrogen-Doped Carbon Dots Derived from Onion Peel (Allium cepa) for Flourescence-Based Detection of Microplastics

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Microplastic (MP) pollution poses an escalating global concern, particularly in the Philippines, which generates over 61,000 metric tons of solid waste daily. This study presents a sustainable and cost-effective method for detecting high-density (HDPE) and low-density polyethylene (LDPE) microplastics using nitrogen-doped carbon dots (N-CDs) synthesized from onion peel and L-cysteine via hydrothermal carbonization. Two precursor ratios (1:1 and 1:0.30 w/w) were evaluated. The resulting N-CDs exhibited bright yellow-green fluorescence (470–500 nm) and excitation-dependent photoluminescence under 365 nm UV light. FTIR and UV-Vis spectroscopy confirmed the presence of nitrogen-containing functional groups and effective graphitization, particularly in the 1:0.30 ratio. Fluorescence imaging revealed stronger intensity and greater stain uniformity in thermally softened MPs treated with 1:0.30 N-CDs, with a peak emission of 10,230.02 a.u. at 2 h and PMT 11—surpassing the 1:1 ratio. Bandgap and absorbance analyses supported the superior optical behavior of the lower-concentration formulation. Image analysis further indicated increased luminescent area over time, and two-way ANOVA confirmed statistically significant effects of heating time and PMT settings ($p < 0.05$). Compared to traditional filtration staining, thermal-assisted application offered enhanced and stable fluorescence. These findings demonstrate the efficacy of green-synthesized N-CDs for MP detection, with potential scalability and environmental applicability. Future work should explore alternative biomass sources and assess N-CD performance under field conditions to optimize environmental sensing strategies.

7.12. Sustainable Design and Engineering of Bio-Based Gold Nanoparticles for Targeted Periodontal Therapy: From Green Synthesis to Scalable Production

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Introduction: Periodontitis is a chronic inflammatory disease triggered by dysbiotic dental biofilms and is a leading cause of adult tooth loss. Conventional treatments (scaling and antibiotics) often leave residual pathogens and biofilms behind. Nanomedicine strategies are thus sought. Gold nanoparticles (AuNPs, ~50–150 nm) are promising carriers: they have excellent bioavailability, can mediate photothermal therapy, and exhibit intrinsic antibacterial/antifungal properties. Functionally, AuNPs can be engineered to target periodontal pathogens while also modulating inflammation and tissue regeneration.

Methods: Through a literature review, we propose to **synthesize AuNPs via the green reduction** of chloroauric acid using plant extracts (e.g., ginger rhizome or tea polyphenols). These bio-capped AuNPs will then be **loaded with periodontal antibiotics** (e.g., metronidazole, doxycycline or chlorhexidine) via surface conjugation or embedding. We may also formulate AuNP–antibiotic complexes in biodegradable hydrogels or coatings for

sustained, localized release. Downstream, the process will be scaled using bioreactor-based production and continuous flow systems.

Expected Results: The proposed AuNP–antibiotic therapy is expected to yield **potent antibacterial activity and enhanced tissue repair**. In vitro, we anticipate the strong inhibition of major periodontal pathogens, while in vivo, similar AuNP systems have demonstrated dramatic effects: for instance, 45 nm AuNPs significantly reduced periodontal inflammation and greatly enhanced new attachment, bone and cementum formation. Likewise, an epigallocatechin-gallate–AuNP hydrogel (E-Au@H) in rats eradicated ~87% of dental biofilm and reduced alveolar bone loss by ~38% under NIR irradiation. We expect our antibiotic–AuNP composites to likewise suppress biofilms, modulate macrophage phenotypes, and promote periodontal regeneration.

Conclusion: This poster will present a combination of green nanotechnology with scalable engineering to tackle periodontitis through green nano-synthesis that is suitable for the large-scale production of nanoparticles. The proposed bio-based AuNP platform could provide a sustainable, targeted therapy that combines strong antimicrobial action with immunomodulation and tissue regeneration, addressing unmet needs in periodontal treatment.

7.13. Targeting Notch Signaling Through miR-34a Modulation: Toward Precision Medicine in COPD Management

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Introduction: Chronic Obstructive Pulmonary Disease (COPD) is a progressive inflammatory lung disorder characterized by irreversible airflow limitation and systemic involvement. While previous studies have implicated microRNA-34a (miR-34a) and Notch1 in COPD pathogenesis, most were restricted to in vitro models, specific exposure types, or genetic association studies lacking clinical correlation. This study explores the diagnostic and therapeutic relevance of the miR-34a–Notch1 axis in clinically phenotyped COPD patients. Modulation of this axis using targeted oligonucleotides such as antagomir-34a, an inhibitor of miR-34a, offers potential for therapeutic intervention.

Methods: A total of 46 participants were enrolled, comprising 23 clinically diagnosed COPD patients and 23 healthy controls, following institutional ethical approval and written informed consent. The mean age of COPD patients was 62.26 $\pm$ 9.17 years, and that of the control group was 47.05 $\pm$ 12.67 years. Group comparisons were adjusted for age using multivariate analysis to reduce confounding. Pulmonary function tests (PFTs)—including Forced Expiratory Volume in 1 s (FEV1), Forced Vital Capacity (FVC), and the FEV1/FVC ratio—were conducted alongside Diffusing Capacity of the Lung for Carbon Monoxide per unit Alveolar Volume (DLCO/VA) and Arterial Blood Gas (ABG) analysis. The serum marker Blood Urea Nitrogen (BUN) was also assessed. Expression levels of miR-34a and Notch1 were quantified using qRT-PCR.

Results: COPD patients exhibited significant upregulation of miR-34a and downregulation of Notch1 ($p < 0.001$). These alterations were correlated with reduced pulmonary function and abnormal ABG parameters. Receiver Operating Characteristic (ROC) analysis revealed high diagnostic accuracy for Notch1 (AUC = 0.974) and FEV1/FVC (AUC = 0.867). ANOVA demonstrated significant variation in Notch1 expression across ABE-defined COPD subtypes, suggesting its potential utility for severity stratification.

Conclusion: These findings support the miR-34a–Notch1 axis as a promising biomarker and therapeutic target. Antagomir-34a shows potential as a precision medicine approach for COPD management.

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