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BOOK OF ABSTRACTS

IMAM 2026

INTERNATIONAL MEETING ON ADVANCED MATERIALS

09TH -11TH MARCH 2026, JASNÁ, SLOVAKIA

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BOOK OF ABSTRACTS

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Preface

On behalf of the IMAM 2026 Organizing Committee, it is our pleasure to present the proceedings of the **International Meeting on Advanced Materials (IMAM 2026)**, held on **9–11 March 2026** in **Jasná, Slovakia**, once again hosted at **Hotel Damian** in the Low Tatras. The conference is organized by the Slovak Chemical Society in cooperation with the Slovak Academy of Sciences.

Building on the success of previous edition, IMAM 2026 continues to provide a platform for researchers working in the field of advanced materials to share their latest findings, discuss innovative approaches, and explore emerging trends in materials science. The primary objective of the meeting remains the promotion of scientific exchange across a broad spectrum of topics related to advanced materials and the fostering of new collaborations within the international research community.

The proceedings contain the full texts of the oral contributions delivered during the conference. The collected papers offer a comprehensive overview of the diverse and significant research topics addressed at the meeting and reflect the high scientific standard of the contributions.

We sincerely thank all authors for submitting their latest research results and thereby contributing to the scientific quality of IMAM 2026. Special appreciation is extended to the reviewers for their careful evaluation of the manuscripts and to the entire organizing team for their commitment and dedication in preparing the event. We also acknowledge the valuable support of our partners and sponsors, whose cooperation significantly contributed to the successful organization of the conference.

We wish all participants an inspiring and productive scientific meeting in the beautiful surroundings of the Low Tatras and hope that IMAM 2026 will once again provide a stimulating environment for new ideas, fruitful discussions, and future collaborations in the field of advanced materials.

Soňa Király

Lectures

Nickel Nanoparticle-Modified Screen-Printed Carbon Electrode as a Promising Approach toward Antibiotic Sensing

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Electrochemical sensors based on screen-printed carbon electrodes (SPCEs) display a practical platform for rapid, low-cost analysis using disposable electrodes. These features make SPCEs attractive for point-of-care diagnostics, environmental monitoring, and on-site quality control [1]. Despite these advantages, the sensitivity and signal stability of SPCE-based sensors depend critically on electrode-interface properties, including charge-transfer kinetics, resistance to surface blocking, and accessible electroactive surface area [2]. Nanomaterial modification has therefore become a key strategy to enhance SPCE performance [3]. Metal nanoparticles can increase the density of accessible active sites, facilitate electron transfer, and improve signal robustness [4]. Nickel nanoparticles (NiNPs) are an attractive material because nickel is relatively abundant and cost-effective while offering favourable electrochemical characteristics. Ni-based nanostructures can improve interfacial conductivity and may promote catalytic behaviour depending on the target analyte and operating conditions [5].

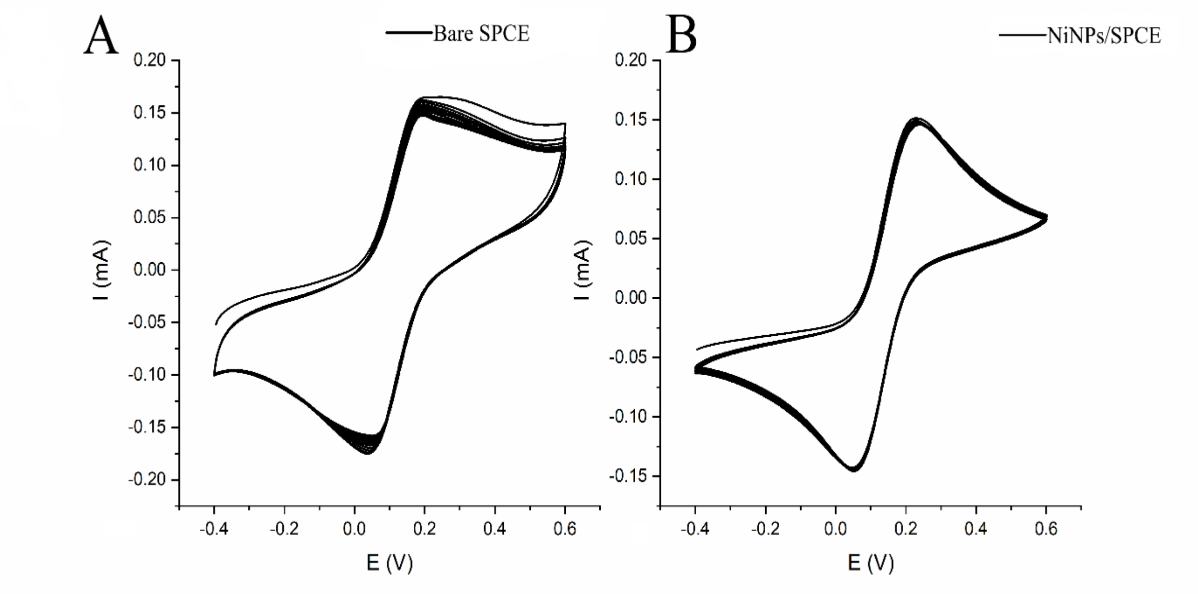

Figure 1 Stability of bare SPCE and NiNPs–SPCE in 5 mM $K_3[Fe(CN)_6]/K_4[Fe(CN)_6]$ (cyclic voltammetry, 10 cycles, 100 mV s^{-1}).

In this study, a bare SPCE and a nickel nanoparticle-modified SPCE were evaluated using the reversible ferri/ferrocyanide redox probe (5 mM $K_3[Fe(CN)_6]/K_4[Fe(CN)_6]$) by cyclic voltammetry (CV). Cycling stability was assessed in a potential window of −0.4 to +0.6 V at 100 mV s^{-1} over 10 consecutive cycles by tracking changes in the anodic peak current. The bare SPCE exhibited significant signal degradation, where the anodic peak current dropped by 22.6% after only 10 cycles. In contrast, the NiNPs–SPCE remained remarkably stable under the same conditions with nearly overlapping voltammograms and only a 3.3% current decrease.

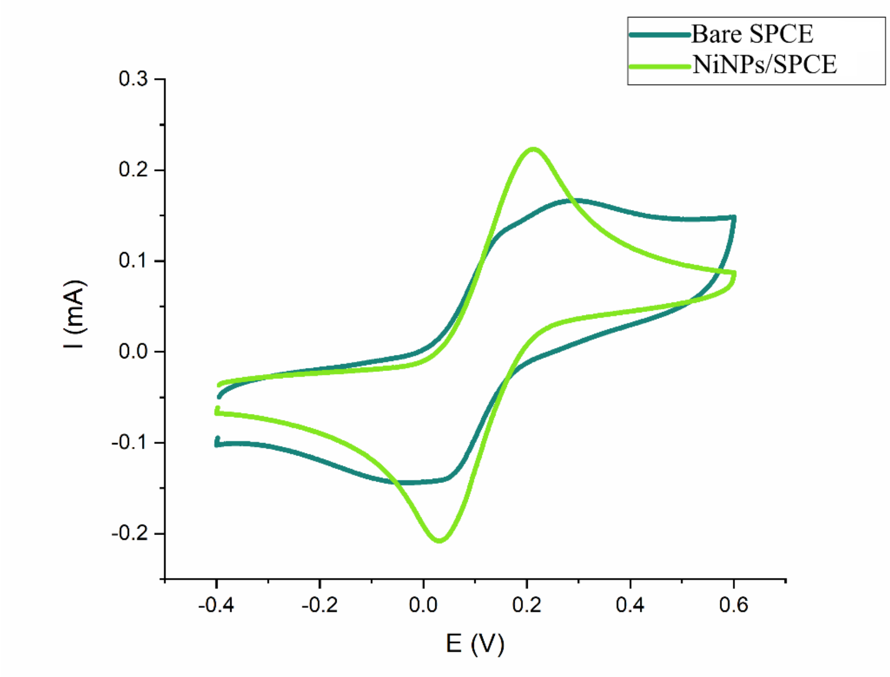

Figure 2 CV responses of bare SPCE and NiNPs–SPCE used for electroactive surface area estimation (5 mM $K_3[Fe(CN)_6]/K_4[Fe(CN)_6]$, 100 mV s^{-1}).

The electroactive surface area, calculated from CV data using the Randles–Ševčík equation, increased from 0.132 cm^2 (bare SPCE) to 0.195 cm^2 (NiNPs–SPCE), representing an approximately 1.5-times increase.

These findings confirm that NiNPs modification improved both stability and effective electroactive area, supporting NiNPs–SPCE as a promising candidate for sensor development, including future applications in antibiotic detection.

Acknowledgements

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Activity-Controlled Polysulfide Thermodynamics and Lean-Electrolyte Engineering in High-Loading Lithium-Sulfur Batteries

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Introduction

Lithium–sulfur (Li–S) batteries represent a prototypical conversion-based electrochemical system, where the redox pathway involves multi-electron reduction of S_8 to Li_2S via soluble lithium polysulfides (Li_2S_x, $4 \le x \le 8$). Unlike intercalation chemistries, the cell voltage and kinetics are governed by phase equilibria and electrolyte non-ideality. The equilibrium potential of the sulfur couple is described by:

$$\boldsymbol{E = E^{\circ} - \frac{RT}{nF} \ln\left(\frac{a_{Li_2S_x}}{a_{Li^+}^2 a_{S_x^{2-}}}\right)}$$

indicating that lithium-ion activity (a_{Li^+}) and polysulfide activity coefficients directly influence plateau positions and voltage hysteresis. Recent fundamental studies confirm that Li^+ solvation free energy shifts redox potentials and modulates phase-transition thermodynamics [1].

Under lean-electrolyte conditions (E/S < 5 µL mg^{-1}), ionic strength increases significantly, promoting ion pairing and altering effective activity coefficients. These concentrated regimes require ion-interaction frameworks beyond dilute Debye–Hückel theory. Changes in solvation structure simultaneously affect Li^+ transference number, ionic conductivity (σ), and diffusion coefficients (D_ps), which directly determine polarization behavior and Butler–Volmer charge-transfer kinetics.

Experimental

From a materials perspective, high-loading sulfur cathodes (>4–6 mg cm^{-2}) impose transport limitations and supersaturation-driven Li_2S nucleation phenomena. The nucleation overpotential is governed by interfacial energy and local Li^+ activity. Polar-functionalized carbon hosts reduce R_ct and facilitate uniform Li_2S precipitation, suppressing passivation [2].

Within the ongoing collaborative research framework, systematic experimental plans include:

- controlled variation of E/S ratio (25 → 15 → 8 → <5 µL mg^{-1}),
- electrochemical impedance spectroscopy (EIS) analysis of R_ct evolution,
- galvanostatic cycling at increasing sulfur areal loadings,
- operando voltage profile analysis to correlate plateau shifts with electrolyte composition,
- evaluation of coulombic efficiency and shuttle current under different ionic strengths.

Results and Discussion

These experiments aim to quantitatively link solvation thermodynamics, ion-activity corrections, and interfacial kinetics to practical energy-density metrics. By integrating electrolyte molecular engineering with rational sulfur-host design, this work outlines a pathway toward high-energy Li–S systems operating under industrially relevant lean-electrolyte conditions [1,3].

Acknowledgements

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High-Efficiency Redox Flow Systems: From Advanced Material Modelling to Scalable Hybrid Storage

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Keywords: Li-ion batteries, Li-S batteries, redox-flow batteries, applied research

Introduction

The advancement of energy storage technologies, specifically lithium-ion (LIB) and redox flow batteries (RFBs), remains a key strategy for the global transition to renewable energy. Current applied research focuses on developing advanced materials, utilizing high-fidelity modelling, and conducting rigorous testing to optimize the performance, safety, and economic viability of these systems. A vital aspect of their adoption is long-term durability and the integration of ethically sourced materials to minimize environmental footprints. Ensuring these batteries can be efficiently recycled or repurposed at the end of their lifecycle is essential for reintegrating valuable secondary raw materials back into the circular economy [1].

To date, lithium-ion batteries have dominated the secondary battery market, being widely implemented in electric mobility, portable electronics, and stationary storage due to their high energy density and proven stability. However, continuous innovation in LIB technology is required, particularly regarding electrode chemistry, electrolytes, and cell architecture. In parallel, RFBs are emerging as a premier solution for grid-scale energy storage. Their capacity for long-duration discharge and rapid response, combined with an extended operational lifespan and high efficiency, makes them highly attractive. In these systems, redox couples and electrolyte compositions are key to determining energy density and costs. This study integrates advanced computational modelling with laboratory validation to develop novel components for Li-S and redox flow battery technologies.

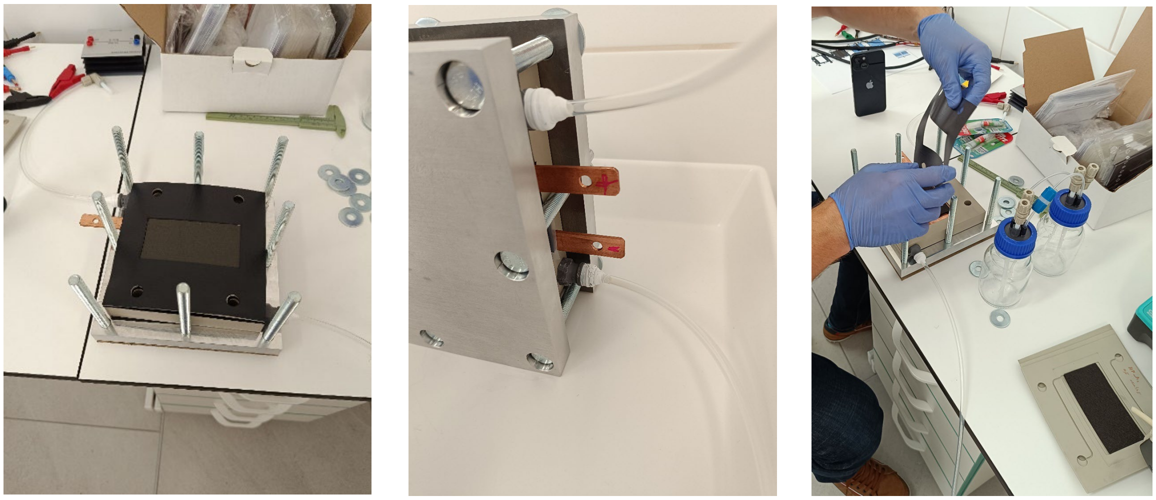

Figure 1 Redox flow battery assembling.

The operational efficiency of redox flow batteries (RFBs) is fundamentally governed by complex electrochemical and mass transport phenomena occurring during charge-discharge cycles. At the heart of performance degradation lies the ohmic resistance, a primary component of the total internal overpotential. This resistance is a multifaceted parameter comprising the ionic resistance of the ion-exchange membrane, the electronic resistance of the bipolar plates and porous carbon electrodes, and the contact resistance at various material interfaces. In high-performance RFB systems, the membrane's ionic conductivity often acts as the dominant ohmic bottleneck, where the mobility of charge-carrying species—such as protons in vanadium systems—must be maximized while maintaining low crossover rates to prevent self-discharge.

During the charging process, an external power source drives the oxidation and reduction of active species within the electrochemical cells, effectively converting electrical energy into chemical potential stored in external tanks. Conversely, the discharge phase involves the spontaneous flow of ions through the membrane and electrons through the external circuit. The efficiency of these processes is significantly impacted by the ohmic drop (V = IxR), which causes a linear deviation from the theoretical Nernstian potential. This voltage loss directly manifests as a reduction in voltage efficiency, particularly at elevated current densities. Furthermore, the interplay between ohmic losses and charge transfer kinetics necessitates the use of advanced diagnostics, such as Electrochemical Impedance Spectroscopy (EIS) (Figure 2), to decouple ohmic contributions from activation and mass-transport polarizations. Optimizing the electrode-membrane assembly to minimize these resistive losses is therefore paramount for achieving the high round-trip efficiencies required for grid-scale energy storage applications [2].

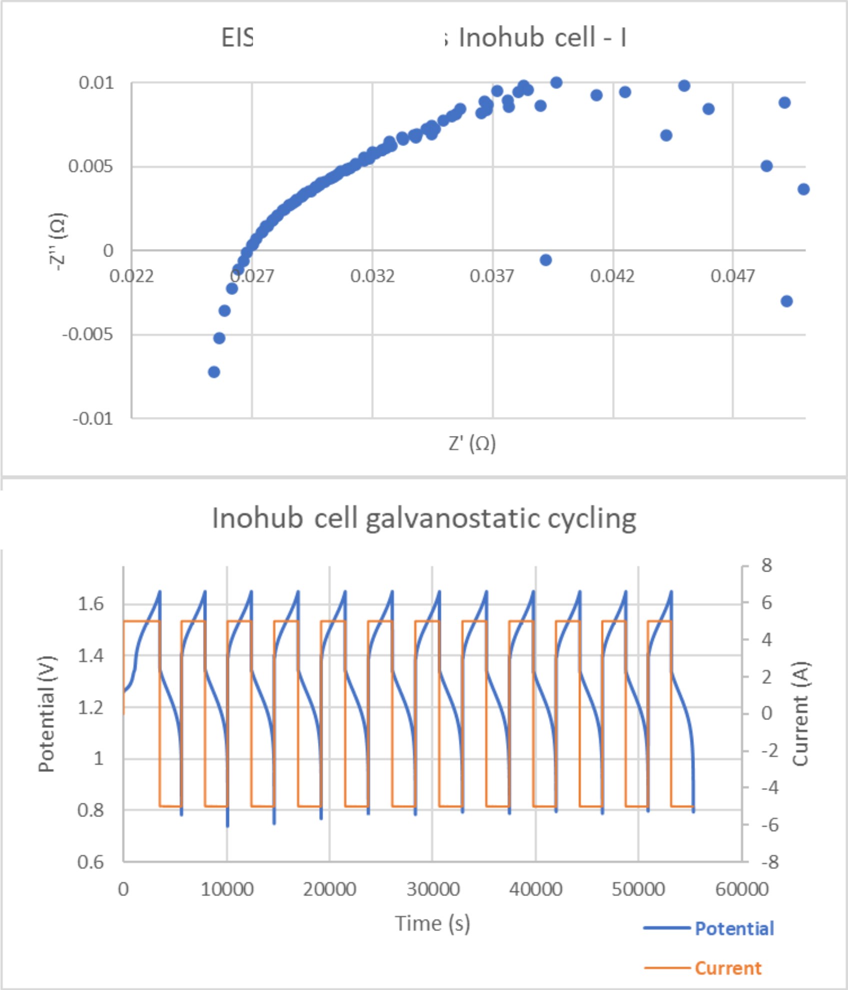

Figure 2 Electrochemical characteristics of redox flow cell – ohmic resistance and charge/discharge cycling.

Computational Modelling in Battery Research

Advanced numerical simulations are essential for deciphering and forecasting electrochemical performance, significantly expediting the discovery of next-generation materials. In the context of Li-ion systems, atomistic tools such as Synopsys QuantumATK permit the precise engineering of cathode, anode, and electrolyte architectures. This methodology facilitates the strategic optimization of materials while drastically cutting R&D expenditures. Within the redox flow battery (RFB) domain, the synergy between machine learning (ML) and high-throughput computational screening (HTCS) has become a vital instrument for material identification. This integrated framework enables the rapid pinpointing of redox-active species, boosting both the operational efficiency and economic feasibility of RFBs. Due to their inherent modularity, RFBs are now primary candidates for grid-scale storage. Current research emphasizes non-aqueous RFBs, which offer broader voltage windows and enhanced cyclic stability. For instance, a recent prototype employing a specific redox couple achieved discharge voltages between 2.25 V and 1.9 V [3]. To assess its scalability, a 2D time-transient reactive transport model was constructed, providing accurate voltage predictions and deep insights into ion transport dynamics.

From a physical perspective, the model distinguished between laminar flow in open channels and porous media flow in felt-filled regions. With a constant flow rate of 1 L/min, the findings indicated a critical need to refine the system's physical definitions. Specifically, the application of the Kozeny-Carman equation proved potentially inadequate for this unique setup, suggesting that alternative governing equations should be explored. Furthermore, the electrolyte permeability must be precisely calibrated, either through direct experimental validation or by using inlet pressure data from empirical measurements to refine the simulation parameters.

Conclusion

The advancement of redox flow battery (RFB) technology represents a critical milestone in the global transition toward sustainable, grid-scale energy storage solutions. This research has demonstrated that the synergy between advanced atomistic modelling and high-throughput computational screening is essential for overcoming current material limitations. By integrating novel simulations with laboratory validation, we have successfully tested new redox-active species that enhance both energy density and economic viability. A significant focus was placed on mitigating ohmic resistance, particularly through the optimization of membrane conductivity and interface architectures, which are vital for maintaining high voltage efficiency. Our 2D time-transient reactive transport models provided crucial insights into species transport and the limitations of traditional physical definitions, such as the Kozeny-Carman equation. These findings emphasize the necessity of precise permeability calibration and refined fluid dynamics to ensure scalability. Ultimately, the transition from theoretical modelling to industrial prototypes confirms that RFBs are a robust, flexible, and sustainable alternative to traditional battery chemistries. By prioritizing ethical sourcing and recyclability, this work ensures that future energy storage systems are as environmentally responsible as they are technically efficient.

Acknowledgments

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Next-Generation Hybrid Energy Storage: Synergizing Li-S and Redox Flow Batteries through Advanced Modelling

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Keywords: Li-ion batteries, Li-S batteries, redox-flow batteries, applied research

Abstract

The global imperative for a carbon-neutral energy landscape necessitates the development of diverse, high-performance electrochemical energy storage systems (EESS). Among the most promising candidates are Lithium-Sulfur (Li-S) batteries and Redox Flow Batteries (RFBs), which offer distinct yet complementary advantages. This work explores the strategic synergy between these two technologies, focusing on their integrated roles in addressing the multi-scale demands of modern power grids and electric mobility.

Lithium-sulfur batteries represent the frontier of high-energy-density storage, theoretically offering 2600 Wh/kg, significantly surpassing conventional lithium-ion systems. However, their commercial integration remains hindered by the complex "shuttle effect" of soluble polysulfides and significant volume expansion during cycling. Conversely, RFBs, particularly vanadium and non-aqueous organic systems, excel in grid-scale applications due to their decoupled energy and power scaling, exceptional cycle life, and inherent safety [1]. The synergy between these systems arises from shared electrochemical principles and material science innovations.

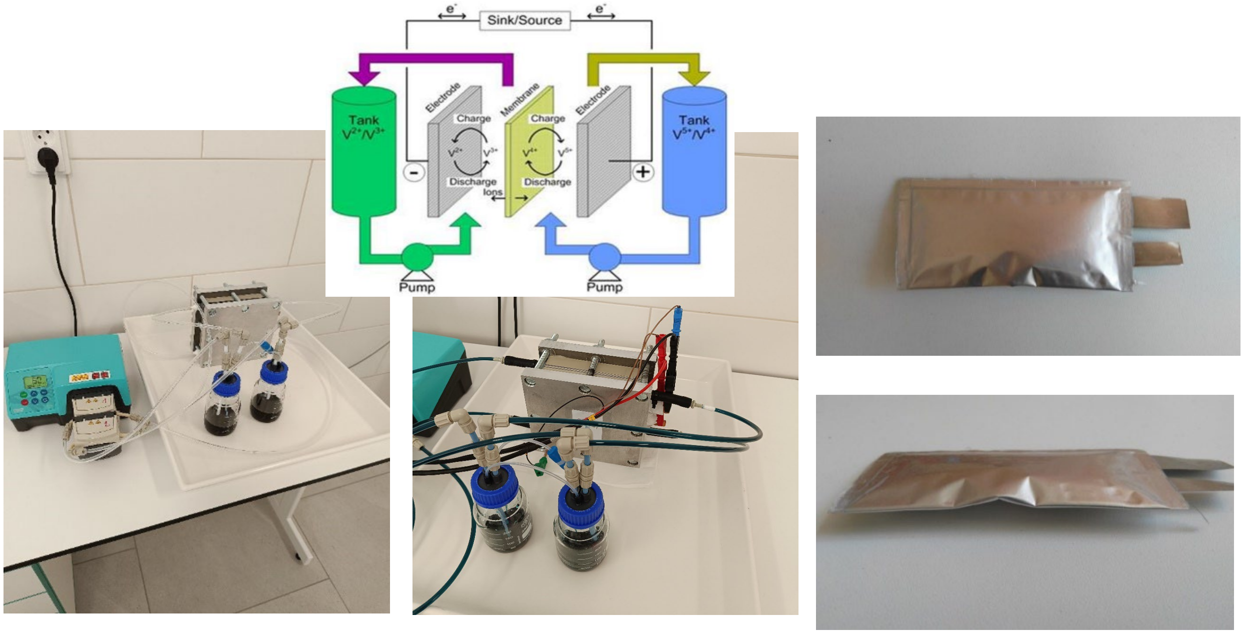

Figure 1 Li-S and redox flow battery prototypes.

Recent research at the Pavol Jozef Šafárik University highlights that advancements in polysulfide chemistry for Li-S cathodes directly inform the development of high-capacity redox-active species for RFBs (Figure 1). By employing advanced atomistic modelling and high-throughput computational screening (HTCS), we have identified novel electrolyte additives and membrane coatings that mitigate parasitic crossover in both systems. Furthermore, the integration of 2D time-transient reactive transport models allows for the precise simulation of ion migration and fluid dynamics, providing a unified framework for optimizing electrode porosity and ohmic resistance.

A key focus of this synergistic approach is the development of hybrid energy storage systems (HESS) that combine the rapid response and high density of Li-S [2] cells with the long-duration stability of RFBs. Such configurations utilize advanced power electronics to buffer peak loads while maintaining baseline grid stability. Moreover, by emphasizing ethically sourced materials and circular economy principles, this research ensures that the lifecycle of both Li-S and RFB technologies aligns with global sustainability goals. The convergence of these technologies through advanced diagnostics, such as operando electrochemical measurements and data monitoring, establishes a robust pathway for the next generation of scalable, cost-effective, and environmentally responsible energy storage.

Acknowledgments

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Correlation and Effect of Deposition Parameters on the Properties of Hydroxyapatite Coatings on Zinc Biomaterials

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This study investigates the correlation between electrochemical and biomimetic deposition parameters and the resulting properties of hydroxyapatite (HAp) coatings on various zinc-based substrates. The primary goal was to achieve a homogeneous and fully adherent coating capable of providing controlled degradation and is expected to improve osteogenesis.

Three different zinc (Zn) substrates were used, namely bulk Zn, foam Zn and Zn powders and the deposition outcomes were compared (Tab. 1). Optimal conditions for bulk Zn deposition were identified as a current density of 1.25 mA/cm^2 for 120 minutes with the addition of EDTA-2Na chelating agent [1]. These parameters ensured strong coating adhesion and hemocompatibility, showing no signs of thrombogenicity. The most successful deposition for Zn foams was achieved using a 30-minute electrochemical process at a constant current of 56 mA, which resulted in a uniform ceramic layer that significantly increased polarization resistance and reduced corrosion rates in simulated body fluids. For powder modification, a biomimetic route (8 hours with strict pH control in SBF) was superior to electrochemical deposition. While electrochemical methods were significantly faster (optimized: 20 min at 0.0038 A/cm^2), they caused HAp to precipitate between the zinc particles rather than directly on them, which was originally anticipated.

Table 1 Comparison of key HAp deposition parameters and resulting coating properties outcomes.

Substrate type	Deposition method	Key optimized deposition parameters	Resulting properties
Zn foam	Electrodeposition	30 min, 56 mA	Homogeneity & high polarization resistance
Bulk Zn	Electrodeposition (+ EDTA precursor)	120 min, 1.25 mA/cm^2	Strong adhesion & hemocompatibility
Zn powder	Biomimetic (SBF)	8 hours, strict pH control	Uniformly coated individual Zn grains
Zn powder	Electrodeposition	20 min, 0038 A/cm^2	Rapid deposition, but HAp is located in between Zn grains

These findings highlight a direct correlation between substrate geometry and ideal processing conditions. Moreover, the use of chelating agents and current density played a crucial role in HAp adhesion strength and coating homogeneity. Coatings effectively slow down zinc degradation, thereby suppressing potential immediate toxic effects during implantation.

Acknowledgements

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Lithium-Sulfur Cathode Batteries: Innovative Solutions for Energy Storage

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The escalating global demand for advanced energy storage systems propelled by electric transportation and portable electronics has highlighted the shortcomings of conventional lithium-ion batteries. Although rechargeable lithium-ion variants have progressed markedly since their commercial launch in 1991, gains in energy density have reached a plateau, emphasizing the imperative for novel chemistries that exceed prevailing storage limits [1,2].

Lithium-sulfur batteries (LSB) present themselves as compelling alternatives, attributed to their exceptional theoretical energy density, plentiful raw materials, affordability, and minimal environmental impact. A prototypical LSB incorporates a lithium metal anode, an organic liquid electrolyte, and a sulfur cathode-leveraging sulfur as an economical, sustainable byproduct of petroleum and mineral refining, with worldwide overproduction surpassing seven million tons yearly. In the discharge phase, elemental sulfur undergoes electrochemical reduction to lithium sulfide through soluble polysulfide intermediates that dissolve within the electrolyte, thereby elevating viscosity and charge-transfer resistance. Although this mechanism holds substantial energy density promise, multiple challenges hinder practical deployment [3,4].

A foremost challenge stems from the intrinsic insulating properties of elemental sulfur, which engender slow electrochemical kinetics, elevated overpotentials, and polarization phenomena. These are exacerbated by the "polysulfide shuttle effect," wherein soluble lithium polysulfides diffuse to the anode, prompting parasitic reduction and the formation of insoluble passivation films. Such processes precipitate irreversible active material loss, anode corrosion, reduced Coulombic efficiency, and curtailed cycle life. Moreover, cycling-induced volumetric expansion of nearly 80% undermines cathode structural integrity, fostering electrical isolation and accelerated capacity decay [5,6]. To surmount sulfur's inherent drawbacks, investigators are engineering conductive carbon-sulfur composites to markedly enhance electrode conductivity [7]. These hybrids generally encapsulate sulfur in porous carbon scaffolds, including graphene or carbon nanotubes, to furnish uninterrupted electron conduits and restrain polysulfides via physical entrapment [8,9] . Carbonaceous materials featuring micro-mesoporous architectures have proven superior for boosting sulfur utilization and cycling durability, owing to their substantial pore volumes and curtailed Li-polysulfide diffusion [10]. Nonetheless, physical entrapment in these frameworks frequently proves inadequate against intermediate migration, given the feeble physisorption between nonpolar carbon and polar polysulfides [11]. Accordingly, chemical anchoring approaches employing polar substances such as metal oxides, nitrides, or heteroatom-doped carbons are under investigation to bolster polysulfide adsorption via robust chemisorption [12].

As depicted in Figure 1 (left), the GlowBox maintains a hermetic, inert argon environment tailored for battery investigations, facilitating the secure manipulation of air- and moisture-sensitive materials. This regulated setting is indispensable to avert contamination during the preparation and fabrication of lithium-sulfur constituents. Figure 1 (right) depicts the procedure for preparing and coating slurries of sulfur-carbon composites onto aluminium foil substrates. The slurry typically consists of the active sulfur-carbon composite, conductive additive and a polymeric binder to ensure homogeneous adhesion to the current collector.

Figure 1(Left) Argon-filled GloveBox used for assembly and handling of oxygen-sensitive battery components. (Right) Photo of sulfur-carbon composite slurries and their coating onto aluminium foil current collectors.

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Molecularly Imprinted Polymer-Based Electrochemical Sensors for Antibiotic Monitoring

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Antibiotic resistance has emerged as one of the most critical global health threats, with projections indicating a substantial increase in resistant infections by 2050 [1]. This alarming trend underscores the urgent need for reliable, sensitive, and accessible analytical approaches for monitoring antibiotics (ATB) in biological, food, and environmental samples [2].

Electrochemical sensors modified by molecularly imprinted polymers (MIPs) represent a promising alternative to conventional chromatographic techniques and offer substantial potential for applications in environmental monitoring, food safety control, and biomedical research [3, 4]. MIPs represent a promising class of synthetic materials characterized by high selectivity, chemical stability, and cost-effectiveness [2]. Their preparation is based on polymerization in the presence of a template molecule, followed by template removal, resulting in the formation of specific binding sites capable of selectively recognizing the target analyte even in complex matrices, as shown in the Figure 1 [5 - 7]. Key interaction mechanisms, including hydrogen bonding, van der Waals forces, and π–π interactions, are considered in relation to their impact on selectivity and analytical performance [8 - 11].

The integration of screen-printed carbon electrodes (SPCEs) with MIPs represents a transformative advancement in the electrochemical sensing of antibiotics within environmental and biological matrices. SPCEs provide a highly versatile, cost-effective, and miniaturized platform that facilitates decentralized, on-site analysis, effectively bypassing the logistical constraints of traditional bulky electrode systems. When these electrodes are modified with MIPs - synthetic receptors engineered with tailored recognition sites - the resulting sensors exhibit exceptional selectivity and sensitivity. This synergy mimics natural antibody-antigen interactions while offering superior chemical and thermal stability compared to biological recognition elements.

Despite these significant advantages, including the ability to achieve high precision in complex samples and the robustness of the polymer matrix under harsh conditions, several technical challenges remain. A primary bottleneck in the development of these sensors is the efficiency of template removal, incomplete extraction of the antibiotic molecule during the synthesis phase can lead to "template leaching," which results in baseline interference and reduced accuracy. Furthermore, because many MIP layers possess insulating properties, optimizing the mass transport and conductivity - often through the incorporation of carbon-based nanomaterials or metallic nanoparticles - is essential to ensuring rapid electron transfer and high analytical performance.

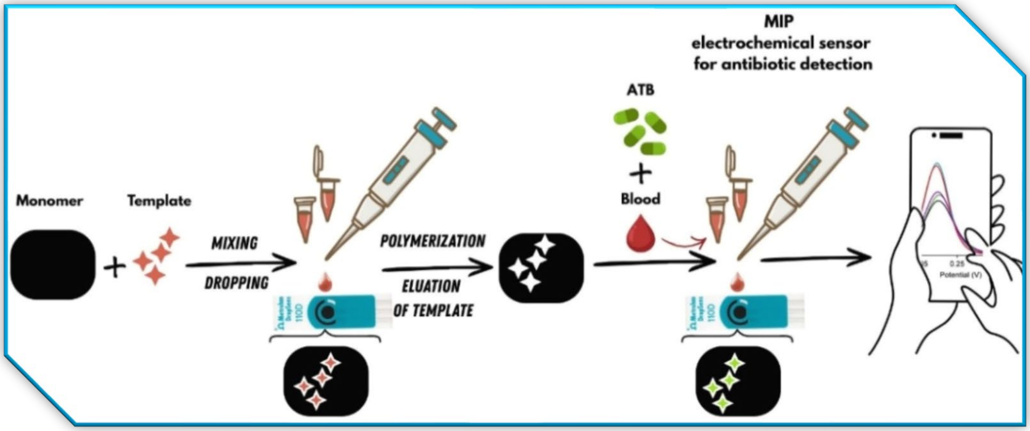

Figure 3 Fabrication strategy and sensing mechanism of an electrochemical MIP-modified SPCE for selective antibiotic detection.

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Conceptual Design of a Non-Enzymatic Electrochemical Multisensor Platform Integrated with a Mobile Application for Distributed Diagnostics

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The growing demand for accessible and decentralized diagnostic solutions has intensified research into compact analytical systems capable of rapid detection of biologically relevant substances outside specialized laboratory environments. Chronic diseases, such as diabetes mellitus, require continuous monitoring of multiple biochemical parameters, thereby emphasizing the need for technologically simple, economically feasible, and user-accessible diagnostic tools.

The presented theoretical concept proposes a portable electrochemical platform based on a multisensor configuration comprising four independently functionalized working electrodes. Each electrode is designed as a dedicated detection unit for a selected bioanalyte (e.g., glucose, insulin, cholesterol, or ascorbic acid), enabling the simultaneous analysis of multiple parameters and allowing for a more comprehensive assessment of metabolic status. The non-enzymatic detection principle relies on electrocatalytically active metal or metal oxide nanoparticles immobilized within a polymer matrix, which ensures mechanical stability, selectivity, and measurement reproducibility.

The proposed system architecture extends beyond the sensing layer by incorporating a mobile software application for real-time processing, visualization, and interpretation of electrochemical signals. Digital transformation of analytical data enables secure storage, further data processing, and potential integration into broader e-health platforms. The concept reflects the interdisciplinary nature of the project, combining electrochemistry, materials engineering, nanotechnology, and software development within Technology Readiness Levels 1–3.

The envisaged system represents a theoretical proof-of-concept framework for a compact, rapid, and cost-efficient device suitable for point-of-care testing. Moreover, the modular design of the multisensor platform provides the basis for future expansion toward additional biomarkers, thereby supporting broader applications in personalized medicine and digital healthcare.

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The Use of Gelatin Sponge Loaded with Sodium Hyaluronate and Silver Sulfadiazine Salt in Treatment of Traumatic Injury in Cat

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Introduction

Wound healing is a crucial process for restoring skin integrity. It is a dynamic process that begins with an inflammatory phase, followed by a phase of proliferation and then differentiation [1]. Wounds that heal by secondary intention healing are more prone to infection, yield poor cosmetic results, and exhibit reduced optimal tissue strength [2]. This condition is an abnormal form of wound healing characterized by continuous localized inflammation excessive collagen synthesis, abnormal collagen turn over, and exaggerated extracellular matrix accumulation. Examples of excessive wound healing include keloid and hypertrophic scars [3]. Factors that influence the treatment and prognosis of open wounds include the time, extent, location and mechanism of injury, degree of wound contamination or infection, limiting factors associated to the client or veterinarian (e.g. finances or experience), and overall health, presence of concurrent injuries and temperament of the patient [4].

Effective wound management is essential not only for restoring tissue integrity, but also for preventing infections, reducing pain, and maintaining animal welfare [5]. Most wounds will progress through the normal stages of healing in expected time, while others may stagnate in the inflammatory phase of healing – also referred to as the "lag phase"- and become chronic [6]. The use of biodegradable materials as external coverings in the absence of skin structures appears to be a supportive mechanism in the wound healing process. Gelatin is a naturally occurring polymer derived from the hydrolytic breakdown of collagen protein. Its unique amino acid composition imparts various medicinal advantages [7]. The substance is a transparent gel that exhibits fissures upon desiccation due to the degradation of collagen within tissues and skeletal structures [8]. Mostly absorbable gelatins sponges are used in various surgical procedures to control bleeding and to show a hemostatic effect [9]. Microorganisms, such as bacteria, viruses, and fungi can evolve overtime, developing resistance to the drugs used to treat them. This process is accelerated by factors such as the misuse and overuse of antimicrobials, poor infection prevention and control practices, and inadequate surveillance [10]. Due to this fact it is recommended to use antimicrobial agents with bactericidal and bacteriostatic effect. This study record treatment plan of devastating skin damage with application of gelatin sponge and supportive topical agents.

Material and methods

Clinical case describes the course of therapy for a devastating injury in a domestic cat (Figure 1A) using conservative management. The main aim of the therapy was to remove dead tissue, exposing the bone base of the proximal phalangeal joints, and to support the repair process of the skin defect while preserving the central footpad and the fifth toe pad. The patient suffered devastating injuries, suspected to have been caused by being caught in a trap resulting in the tearing of the surface and muscle layers in the distal superficial structures associated with desiccation of the granulation bed after exposure of the subcutaneous tissue in the metacarpal bone area. The patient was admitted to the Small Animal Clinic, University of Veterinary Medicine and Pharmacy in Košice, where the condition of the limb was assessed, samples were taken for microbiological culture, with *Staphylococcus intermedius* found, which is a common finding in skin defect cultures, followed by supportive therapy aimed at granulation tissue formation and epithelialization of exposed structures. In this clinical case, permanent coverage of the skin defect site was chosen to prevent the exposed structures from drying out. The primary contact layer of the external covering consisted of a gelatin sponge in combination with sodium hyaluronate and silver sulfadiazine salt in cream form. The secondary layer consisted of a synthetic cotton wool layer and the third layer consisted of self-adhesive bandage. Dressings were changed every 24 to 72 hours, depending on the healing phase and secretion. In the primary phases of the healing process, significant changes in macroscopic indicators were observed, with rapid suppression of the inflammatory response and secretion of exposed structures. The following phases of the skin defect healing process were characterized by rapid closure in relation to the contraction of the wound edges (Figure 1B, C), which contributed to the early closure of the skin defect. In the treatment of the clinical case, gelatin sponge – a matrix corresponding to the size of the defect (Surgispon Standard, Aegis Lifesciences, India) enriched with sodium hyaluronate and silver sulfadiazine salt (Ialugen Plus, IBSA, Italy) – was repeatedly applied at each changing of bandage. These active ingredients ensured hydration of the damaged area, suppression of the inflammatory response, a bacteriostatic effect, and promoted epithelialization. The healing of the skin defect by conservative management took place over a period of 31 days (Figure 1D) with continuous closure of the skin defect while ensuring the functionality of the affected limb. The effectiveness of gelatin as a hemostatic agent enriched with active supporting components was demonstrated by the reduction of typical symptoms occurring during the healing of chronic skin defects in cats.

Discussion

Traumatic soft tissue injuries pose a challenge in healthcare due to the risk of complications that require effective therapeutic procedures [11]. Many standard therapeutic procedures for traumatic injuries do not result in sufficient healing, which leads to prolonged healing times and excessive scar tissue formation [12]. The process of epithelialization is a fundamental component of wound healing. It is considered a decisive parameter for successful wound closure, as a wound cannot be considered closed until it has undergone re-epithelialization. In chronic wounds, the epithelialization process is disrupted, increasing the risk of secondary infection and fluid loss and affecting the overall duration of wound treatment [13, 14].

Gelatin is used in many biomedical fields, including wound healing and controlled drug delivery, demonstrating excellent biodegradability and biocompatibility [15]. Specifically, in the context of chronic wound healing, its effects have been demonstrated in rapid healing processes through the stimulation of wound contraction and re-epithelialization [16]. In a study by Doostmohammadi et al. [17], gelatin materials were examined in wound healing, where it was demonstrated that these scaffolds represent a promising option in wound therapy. Such a scaffold mimics the structure of the ECM, gelatin promoting cell migration and proliferation, which ultimately resulted in better *in vivo* healing.

Conclusion

These results point to the possibility of using gelatine as a promising biodegradable material in the healing process of chronic and traumatic soft tissue injuries. This material provided the possibility of rapid re-epithelialization of the defect and closure of the chronic wound, while showing no negative effects, so it can be considered safe, with a favourable functional and cosmetic effect achieved.

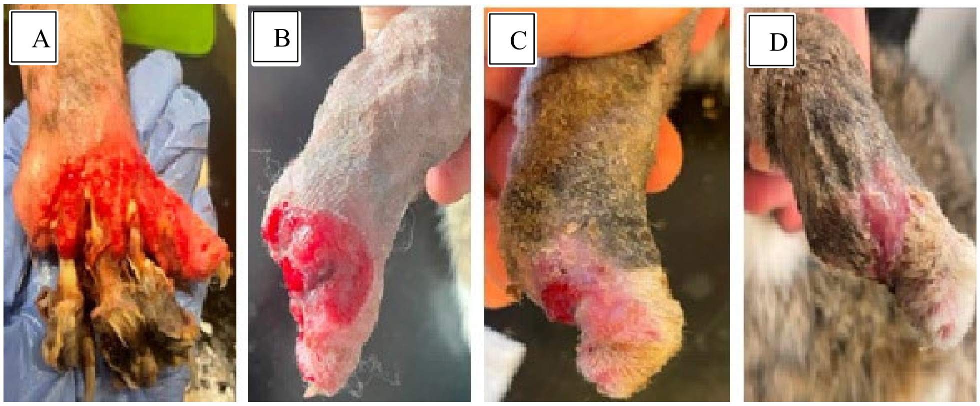

Figure 1 (A): Initial condition, devastating injury with exposed bone, (B): Presence of vital granulation tissue (day 14), (C): Presence of epithelialization of the defect (day 21), (D): Complete closure of the defect with a thin pink scar on day 31.

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Interfacial Charge-Transfer, Non-Ideal Electrolyte Thermodynamics and Transport Coupling in Advanced Lithium–Sulfur Conversion Systems

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Introduction

Lithium–sulfur (Li–S) batteries operate through a sequence of electrochemically and chemically coupled reactions involving dissolution, diffusion, disproportionation, and precipitation processes. The overall electrochemical response is governed by the interplay between **charge-transfer kinetics**, **mass transport of soluble polysulfides**, and **non-ideal electrolyte thermodynamics**.

At the electrode interface, sulfur reduction proceeds via multi-electron transfer steps, whose kinetics can be described by the Butler–Volmer equation:

$$i = i_0 \left[\exp\left(\frac{\alpha nF\eta}{RT}\right) - \exp\left(-\frac{(1-\alpha)nF\eta}{RT}\right)\right]$$

where the exchange current density i_0 depends on the activities of Li^+ and polysulfide species, electronic conductivity of the host matrix, and density of active catalytic sites. In concentrated ether-based electrolytes, activity coefficients deviate significantly from unity, requiring correction of kinetic expressions using activity-based formulations. The reaction free energy and plateau potentials are therefore modulated by solvation-controlled changes in lithium-ion chemical potential [1].

Mass transport of Li_2S_x species follows Nernst–Planck behavior:

$$J_i = -D_i \nabla c_i - \frac{z_i D_i F}{RT} c_i \nabla \phi$$

where diffusivity D_i is strongly influenced by viscosity, ion pairing, and solvation shell structure. In highly concentrated or weakly solvating electrolytes, ion aggregates reduce the concentration of "free" polysulfides, lowering shuttle current but simultaneously altering diffusion coefficients and effective ionic conductivity [4]. Such systems display pronounced non-ideality, where ionic strength modifies activity coefficients via ion–ion interaction frameworks beyond classical Debye–Hückel treatment.

Experimental

At high sulfur loadings (>5 $mg\ cm^{-2}$), polarization arises from both diffusion limitations and increased charge-transfer resistance (R_ct). Li_2S precipitation is governed by classical nucleation theory, where the nucleation barrier ΔG^* depends on interfacial energy and supersaturation ratio. Polar and catalytic host materials reduce interfacial energy, lower nucleation overpotential, and promote uniform Li_2S deposition, mitigating passivation phenomena [2].

Simultaneously, at the lithium metal anode, electrolyte reduction leads to the formation of a solid electrolyte interphase (SEI). The SEI composition determines lithium-ion flux homogeneity and interfacial impedance evolution. Electrolyte molecular structure and salt chemistry critically influence reduction pathways and resulting SEI transport properties [3]. Concentrated electrolyte systems have been shown to alter Li^+ solvation structures in ways that improve morphological stability and suppress dendritic growth [4].

Within the ongoing experimental research program, systematic investigations are planned to quantitatively couple thermodynamic and kinetic descriptors with measurable electrochemical parameters:

- Variation of salt concentration and solvent composition to tune solvation free energy and ionic strength.
- Determination of ionic conductivity (σ) and viscosity.

- Electrochemical impedance spectroscopy (EIS) modeling to separate bulk resistance, R_ct, and Warburg diffusion contributions.
- Cyclic voltammetry to evaluate exchange current density and activation polarization.
- Long-term galvanostatic cycling under controlled areal capacities to correlate interfacial stability with electrolyte non-ideality.
- Comparative analysis of additive-modified systems targeting SEI stabilization and polysulfide immobilization.

Results and Discussion

By integrating activity-corrected thermodynamics, transport theory, and interfacial kinetic modeling, this work establishes a mechanistic framework linking electrolyte molecular design with measurable electrochemical descriptors. The results emphasize that achieving stable, high-energy Li–S batteries requires simultaneous regulation of ion transport, interfacial charge-transfer, and non-ideal solution behavior, rather than isolated optimization of individual components [1,4,5].

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Bioactive and Antimicrobial Ceramic Coatings for Titanium Implants: Bridging Osseointegration and Infection Control

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Titanium and its alloys are among the most reliable metallic biomaterials used in orthopaedic implants due to their excellent biocompatibility, corrosion resistance, high mechanical strength, and low density. However, titanium is considered bioinert, which may limit direct bone bonding and lead to fibrous capsule formation, compromising optimal osseointegration. These limitations led to the development of techniques to functionalize titanium implant surfaces by modifying their structure, composition, and morphology while preserving their mechanical properties [1].

To overcome these limitations, various surface functionalization strategies have been developed, including laser treatment, acid etching, sandblasting, and surface impregnation. Among these approaches, ceramic coatings are currently regarded as one of the most effective strategies [2]. To enhance the bioactivity of titanium implants, ceramic coatings such as hydroxyapatite or bioglass are deposited onto the implant surface. These coatings promote osseointegration and support bone healing. However, there is one additional critical challenge in orthopaedics. Biocompatible and bioactive surface of the orthopaedic implants not only promotes adhesion of host cells but also allows the adhesion and growth of microorganisms. This may result in implant-associated infection (IAI), which is considered as the most common cause of the implant failure.

Following initial colonisation, microorganisms form organised communities of microbial cells embedded within a self-produced extracellular polymeric matrix known as biofilm. This matrix protects bacteria from antimicrobial agents and host immune responses while promoting the coaggregation of different microbial species. The localized anaerobic microenvironment within the biofilm further supports the proliferation of peri-implant pathogens, contributing to the development of more severe infections [3].

Systemic antibiotic therapy which is the most traditional strategy for IAI treating is often insufficient due to limited vascularisation at the implantation site and poor antibiotic penetration into biofilms. Furthermore, high systemic dosage of antibiotics can cause toxicity and impair bone regeneration. As the result, revision surgery is frequently required, increasing patient morbidity and healthcare costs. In the most serious cases, IAI can lead to amputation or life-threating consequences. Preventing early biofilm formation through antibacterial surface modification therefore represents a critical strategy [4].

One promising approach involves loading ceramic coatings with antibacterial agents such as antibiotics, organic compounds, metal ions, or nanoparticles. Such systems enable controlled release of the drug directly to the implantation site through diffusion and dissolution or degradation of molecules in the coating. These coatings can release drugs at therapeutic concentrations capable of eliminating bacteria both at the implant surface and in the surrounding tissue. Because first 24 hours are the most crucial for the biofilm formation, rapid initial release of supra-inhibitory antibiotic concentrations can successfully prevent the infection [4, 5].

Commonly used antibiotics for local delivery include penicillin, chlortetracycline, streptomycin, vancomycin, tobramycin and gentamicin [4, 6]. Hydroxyapatite has proven to be an effective antibiotic carrier, especially for gentamicin, which is the most extensively studied antibiotic in implant coatings [7]. Neut et al. [8] demonstrated the broad-spectrum antibacterial activity of a gentamicin coating under *in vitro* conditions, demonstrating its effectiveness in preventing *Staphylococcus aureus* infection in a cementless total hip arthroplasty model. Similarly, Alt et al. [9] showed in a rabbit study that a gentamicin-hydroxyapatite composite significantly reduced infection rates compared with uncoated joint replacements. Gentamicin-loaded implants have demonstrated promising preliminary results also in the patient trials. However, there are still a lot of unresolved issues associated with optimal release kinetics and methodology for antibiotic inclusion to the hydroxyapatite coating [4]. High local concentrations of antibiotics can act cytotoxic [10].

Based on the research by ter Boo et al. [10], Table 1 compares the three most commonly used antibiotics gentamicin, vancomycin and tobramycin with a focus on their acceptable concentrations and their effect on osteoblast cell viability and proliferation.

Table 1 Comparison of the cytotoxic concentrations of antibiotics used in orthopaedic implants [10].

Parameter	Gentamicin	Vancomycin	Tobramycin
Type of antibacterial activity	Concentration-dependent	Time-dependent	Concentration-dependent
Non-cytotoxic concentration	≤ 30 µg/mL	≤ 2000 µg/mL	> 500 µg/mL
Cytotoxic concentration	> 2000 µg/mL	Very low cytotoxicity even at high concentrations	Not reported
Safe *in vivo* serum concentrations*	4.5 µg/mL	35.1 µg/mL	Not reported

*Values correspond to peak therapeutic serum concentrations in a rat model that did not negatively affect fracture healing.

Among antibiotics used for local delivery in orthopaedic implant coating, gentamicin remains the most clinically established, but its use is limited by concentration-dependent cytotoxicity, whereas vancomycin and tobramycin exhibit substantially higher cytocompatibility, supporting their potential in future antibacterial coating systems [10].

A major concern with antibiotic-loaded coatings is the development of bacterial resistance. Consequently, current research is focusing on inorganic agents, such as metal ions and their oxides, as alternatives. The well-known Ag^+ ion exhibits multiple antibacterial mechanisms, reducing the likelihood of resistance development. Similarly, Zn^{2+} and Cu^{2+} are also used in antibacterial coatings, as they display significant antibacterial properties and ability to destroy bacterial cell membranes [4].

The clinical effectiveness of antimicrobial coatings varies significantly depending on their mechanism of action. According to a recent network meta-analysis, local antibiotic carriers demonstrate superior efficacy in preventing IAI compared to other preventive strategies. The analysis included 3,592 patients and evaluated several technologies, including DAC-hydrogel (Defensive Antibacterial Coating) applied to the implant surface immediately prior to implantation, as well as gentamicin-, iodine-, and silver-loaded coatings. Among these DAC-hydrogel emerged as the most effective technology, followed by gentamicin-coated surfaces (Figure 1). While inorganic ions such as iodine and silver also significantly reduce infection risk, their clinical impact appears more variable. Despite numerous *in vitro* studies demonstrating the strong antimicrobial activity of silver, its clinical evidence suggests more limited *in vivo* benefits [11].

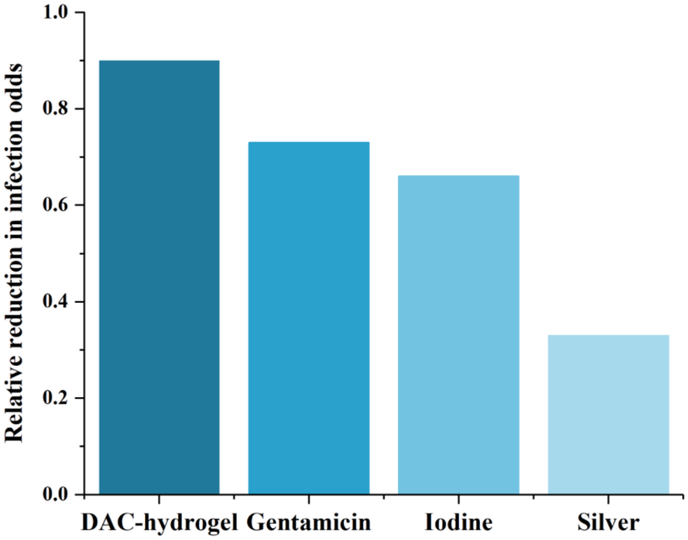

Figure 1 Relative reduction in infection odds (calculated as 1 – odd ratio) compared with non-coated implants [11].

These findings suggest that achieving supra-inhibitory local antibiotics concentrations during the initial phase after implantation of titanium implants remain the most effective strategy for infection prevention. Metallic ion-based coatings may serve as a complementary approach, providing additional antimicrobial protection while minimizing the risk of resistance

Acknowledgements

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Sustainable Energy Storage: Organic Electrolytes in Redox Flow Batteries

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Redox flow batteries (RFBs) are considered promising systems for large-scale electrical energy storage and grid integration of renewable energy owing to their scalability, safety, and independent control of power and capacity. Nevertheless, conventional inorganic RFB chemistries such as vanadium-based systems face limitations including high cost, material availability concerns, electrolyte toxicity, and crossover effects, which motivate the exploration of alternative redox-active materials [1]. In this context, organic electrolytes have emerged as attractive candidates because they are composed of earth-abundant elements and offer broad structural diversity and synthetic tunability, enabling rational optimization of solubility, redox potential, reaction kinetics, and electrochemical reversibility [2]. Among various molecular classes, quinones represent one of the most intensively studied families due to their favorable redox reversibility and ability to function as either negative or positive electrolytes, although their stability and solubility remain key challenges [3].

Furthermore, electrolyte composition and solvent environment strongly influence battery performance, particularly in non-aqueous systems where wider electrochemical windows can enable higher cell voltages and energy densities. Solvent properties such as polarity and viscosity directly affect conductivity, mass transport, and reaction kinetics of redox-active species, highlighting the importance of electrolyte engineering [4]. Consequently, the rational molecular design of organic redox species together with optimization of solvent systems is a central research direction for the development of next-generation high-performance RFB technologies [2].

Materials and methods

To evaluate the suitability of organic redox-active molecules for flow battery applications, preliminary electrochemical characterization was performed prior to full cell testing. The objective of these initial experiments was to determine fundamental parameters such as redox potential, reversibility of electron-transfer processes, and mass-transport behavior of selected organic electrolyte candidates. Electrochemical measurements were carried out using cyclic voltammetry in a conventional three-electrode cell configuration. A glassy carbon electrode served as the working electrode due to its wide potential window and chemical stability. A platinum electrode was used as the counter electrode, while an Ag/AgCl reference electrode provided stable potential control. Prior to each measurement, the working electrode was polished and cleaned to ensure reproducibility and minimize surface effects.

Initial cyclic voltammograms were recorded over a broad potential range to identify electrochemically active regions and define stable operating windows for the investigated compounds. Subsequently, scan-rate-dependent measurements were performed to evaluate electron-transfer kinetics and distinguish diffusion-controlled processes from possible adsorption phenomena. The dependence of peak current on scan rate was analyzed to estimate diffusion-related parameters relevant for flow battery operation.

These preliminary electrochemical measurements represent the first stage of a broader experimental workflow. Based on the obtained electrochemical characteristics, selected organic electrolytes will subsequently be tested in laboratory-scale redox flow battery single cells, where charge–discharge performance, cycling stability, and electrolyte compatibility will be evaluated under practical operating conditions.

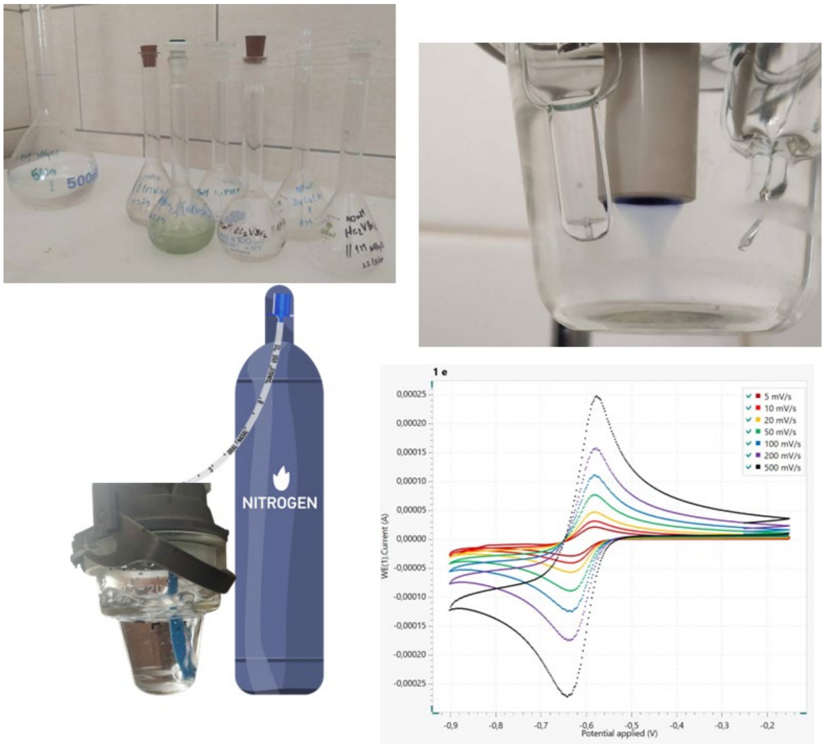

Figure 4 Experimental workflow for preparation and electrochemical characterization of organic electrolytes using cyclic voltammetry prior to redox flow battery testing.

Conclusion

Organic electrolytes represent a promising pathway toward sustainable and scalable redox flow battery technologies due to their structural flexibility and potential environmental benefits. Preliminary electrochemical characterization using cyclic voltammetry provides essential insight into redox behavior and transport properties, enabling informed selection of candidate materials before implementation in full battery systems. Future research will focus on translating these findings into experimental testing in laboratory redox flow battery cells to evaluate long-term cycling stability, energy efficiency, and operational performance. The integration of molecular design, electrolyte engineering, and cell-level experimentation is expected to contribute significantly to the advancement of sustainable energy storage technologies.

Acknowledgements

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Structural Design of Host Matrices for Lithium-sulfur Batteries: Toward High Energy and Stable Li-S System

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Introduction

Lithium-ion batteries (LIBs) dominate current energy storage systems, yet their practical energy density (100–250 Wh kg^{-1}) remains insufficient for long-range electric mobility and is approaching intrinsic limits. Further cost reduction is constrained by the use of expensive transition metals in cathodes, raising both economic and sustainability concerns. These limitations motivate the development of next-generation high-energy and transition-metal-free battery systems [1]. Lithium–sulfur (Li–S) batteries are considered a promising high-energy system due to the high theoretical capacity of sulfur (1672 mAh g^{-1}) and the resulting energy density (~2500 Wh kg^{-1}). However, their practical application is limited by low conductivity of sulfur and Li_2S, polysulfide shuttling, rapid capacity fading, and instability of the lithium-metal anode [2]. To address these challenges, extensive research has focused on the rational design of sulfur host matrices capable of enhancing electrical conductivity, suppressing polysulfide dissolution, and stabilizing multistep conversion reactions. Porous carbon-based materials have been widely investigated as sulfur hosts due to their high surface area, tunable pore structure, and good electronic conductivity [3]. Structural confinement within micro- and mesoporous networks enables physical trapping of lithium polysulfides, while hierarchical architectures facilitate sulfur loading and electrolyte accessibility [3], [4]. Beyond physical confinement, chemical interactions between the host matrix and polysulfide species play a decisive role in improving electrochemical stability. Surface functionalization and heteroatom doping (e.g., nitrogen or sulfur) introduce polar sites that enhance polysulfide chemisorption and modify local electronic structure, thereby improving redox kinetics and suppressing shuttle behavior [4]. In addition, covalent stabilization strategies and Lewis base-type interactions have been shown to strengthen sulfur anchoring and promote more efficient oxidation–reduction pathways during cycling [5], [6]. A deeper understanding of the complex multistep sulfur redox mechanism, including the stability of higher-order polysulfides and their interfacial transformations, is therefore essential for the rational design of advanced host materials [6]. Despite significant progress, achieving high sulfur loading, efficient polysulfide immobilization, and long-term cycling stability simultaneously remains a challenge. Consequently, the development of structurally optimized host matrices with tailored porosity and surface chemistry represents a key direction toward practical implementation of high-performance Li–S battery systems.

Experimental

In this work, different types of host matrices with tailored porous architectures were investigated as sulfur carriers in Li–S cathodes. The objective was to evaluate how matrix structure influences electrochemical redox behavior, with particular emphasis on cyclic voltammetry analysis as a probe of reaction kinetics and reversibility. Porous host matrices with controlled micro-/mesoporous architectures were synthesized via conventional chemical routes and subsequently employed as sulfur carriers. Sulfur incorporation was achieved through melt-diffusion to ensure homogeneous distribution within the pore network. Composite cathodes were prepared by mixing the sulfur-loaded host material with conductive carbon and polymeric binder (PVDF) in an appropriate weight ratio. The resulting slurry was homogenized in an organic solvent (NMP), cast onto aluminum foil current collectors, and dried under vacuum. Electrochemical cells were assembled using lithium metal as the counter/reference electrode and a conventional ether-based electrolyte consisting of 0.7 M lithium bis(trifluoromethanesulfonyl)imide (LiTFSI) and 0.25 M lithium nitrate ($LiNO_3$) dissolved in a 1,2-dimethoxyethane (DME) and 1,3-dioxolane (DOL) mixture with a volume ratio of 2:1. Electrochemical characterization was carried out by cyclic voltammetry (CV) at a scan rate of 0.1 mV s^{-1} within a voltage window of 1.8–2.8 V.

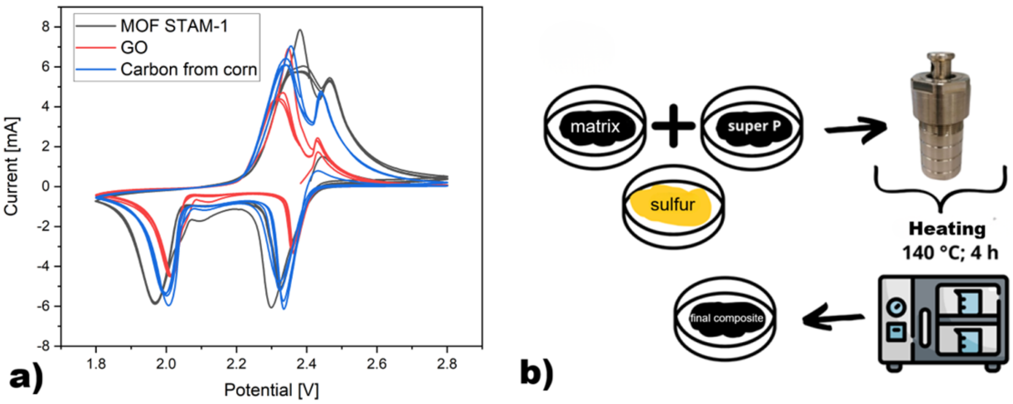

Figure 5 (a) Cyclic voltammetry curves of Li–S cathodes with different host matrices recorded in the voltage window 1.8–2.8 V. (b) Schematic illustration of sulfur incorporation into the host matrix and composite preparation via melt-diffusion at 140 °C for 4 h.

Redox Characteristics of Sulfur Confined in Porous Matrices

Cyclic voltammetry reveals the characteristic two-step reduction of sulfur in Li–S systems, with cathodic peaks at approximately 2.3 V and 1.9–2.0 V corresponding to the formation of higher-order polysulfides and their subsequent conversion to Li_2S_2/Li_2S, respectively. The anodic peak at ~ 2.3–2.4 V represents the reverse oxidation process. While all matrices exhibit the same redox mechanism, clear differences in peak intensity and separation are observed. The MOF-based electrode shows higher peak currents and reduced peak-to-peak separation ($\Delta\ E_p$), indicating enhanced charge-transfer kinetics and lower polarization. In contrast, the GO-based system exhibits broader peaks and slightly increased polarization, suggesting slower reaction kinetics. The more pronounced second reduction peak for the porous matrices indicates improved stabilization and confinement of intermediate polysulfides, leading to more efficient conversion to Li_2S_2/Li_2S. The good overlap of successive cycles confirms acceptable reversibility, with the MOF-derived matrix demonstrating the most stable redox response. These results confirm that host matrix architecture critically influences sulfur redox kinetics and polarization behavior in Li–S cathodes.

Conclusion

Lithium–sulfur batteries remain one of the most promising candidates for next-generation high-energy storage systems beyond conventional lithium-ion technology [1]. However, their practical deployment is still limited by polysulfide shuttling, sluggish redox kinetics, and structural instability [7]. The present study demonstrates that host matrix architecture significantly affects sulfur redox behavior. Cyclic voltammetry analysis confirms that porous matrices with tailored structural features reduce polarization, enhance charge-transfer kinetics, and improve redox reversibility compared to purely carbonaceous systems. These findings highlight the critical role of matrix design in stabilizing conversion reactions in Li–S cathodes. Future work will focus on systematic galvanostatic capacity evaluation, long-term cycling stability, and reproducibility of the electrochemical performance. Particular attention will be devoted to optimizing sulfur loading and assessing rate capability under practical operating conditions. The ultimate goal of the ongoing research is the selection of the most suitable host matrix and the development of a functional Li–S prototype cell based on the optimized material system.

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Achieving European Battery Resilience by 2030: A Strategic Roadmap for Regulatory Compliance

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A sustainable battery ecosystem is pivotal to the European Union's clean energy transition and its 2050 climate neutrality mandate under the Green Deal [1]. While lithium-ion batteries are central to electric mobility and grid storage, escalating demand and heavy reliance on imported critical raw materials (CRMs), notably lithium, cobalt, and nickel, create profound geopolitical and environmental vulnerabilities [2, 3]. Battery material sourcing and production impose heavy environmental and social costs, from water-intensive lithium extraction to ethical risks in cobalt mining [4]. Furthermore, Europe's current recycling infrastructure is insufficient to meet 2030 demand [5]. To mitigate these vulnerabilities, the EU has introduced a robust regulatory framework, comprising the Battery Regulation (EU) 2023/1542 [6], the Critical Raw Materials Act (CRMA) [7], and the Eco-design for Sustainable Products Regulation [8] to enforce sustainability, enhance material traceability, and foster a resilient, self-sufficient battery ecosystem. Although Regulation (EU) 2023/1542 introduces stringent standards for lifecycle management, persistent bottlenecks in supply security and the scalability of recycling remain.

The strategic positioning of the European Union's battery supply chain in relation to the 2030 regulatory objectives has been evaluated by Gianvincenzi et al. [9]. An assessment of domestic resource availability, recycling capacities, and market barriers reveals key strategic advantages and systemic weaknesses within the current EU framework. According to their results, accelerating the development of local resources and optimizing recycling technologies are essential priorities for securing stable supply chains.

The study by Gianvincenzi et al. [9] utilized a comparative mapping approach to ensure methodological alignment with formal European legal requirements. Central to this evaluation are the targets derived from the Battery Regulation (EU) 2023/1542 [6] and the Critical Raw Materials Act (EU) 2024/1252 [7], hereafter identified as Battery Objectives (BO) and Critical Objectives (CO). These regulatory benchmarks, organized into Tables 1 and 2, establish some structured criteria for verifying that the proposed strategic priorities are both consistent with and responsive to current EU policy mandates.

Table 1 Battery Regulation (EU)2023/1542 Objectives (BOs) [9].

Objectives		Targets
BO1	Responsible sourcing of raw materials	Implementation of due diligence for risk management in the supply chain, ensuring socially and environmentally responsible sourcing
BO2	Reduction of carbon footprint	By 2024: Mandatory carbon footprint declaration for batteries. Future: Compliance with specific reduction targets (to be detailed in further regulations)
BO3	Recycled content requirements for new batteries	By 2030: 12 % cobalt (Co), 4 % lithium (Li), 4 % nickel (Ni) from recycled sources By 2035: 20 % Co, 10 % Li, 12 % Ni from recycled sources
BO4	Performance and durability standards	Set minimum performance and durability criteria for batteries used in specific applications
BO5	Design requirements for battery disassembly	Facilitate disassembly, reuse, and recycling

BO6	Battery Labelling and Digital Passport	By 2026, mandatory battery labelling with performance, safety, and environmental information; by 2027, digital passport with more detailed battery data.
BO7	Battery Collection Targets	Portable batteries: 45 % by 2023, 63 % by 2027, 73 % by 2030. LMT batteries: 51 % by 2028, 61 % by 2031. EV and industrial batteries: 100 % collection required. Mandatory take-back schemes.
BO8	Recycling Efficiency Targets	By 2025: 75 % for lead-acid, 65 % for lithium-based, 80 % for nickel-cadmium, 50 % for other batteries. By 2030: 80 % for lead-acid, 70 % for lithium-based.
BO9	Material Recovery Targets	By 2027: 90 % for Co, copper (Cu), Ni, and lead (Pb); 50 % for Li. By 2031: 95 % for Co, Cu, Ni, and Pb; 80 % for Li.
BO10	End-of-life treatment for batteries	Ensure removal and proper recycling of end-of-life batteries

Table 2 Critical Raw Material Act Regulation (EU)2024/1252 Objectives (COs) [9].

Objectives		Targets
CO1	Secure Supply of Strategic Raw Materials	By 2030, the EU aims to extract at least 10 % of its annual consumption of strategic raw materials from within the Union.
CO2	Increase Processing Capacity	Ensure the EU processes at least 40 % of its annual consumption of strategic raw materials by 2030.
CO3	Boost Recycling Capacity	Achieve a recycling capacity within the EU that meets at least 25 % of its annual consumption of strategic raw materials by 2030.
CO4	Diversify Import Sources	Limit reliance on any single non-EU country to supply no more than 65 % of the Union’s annual consumption of any strategic raw material by 2030.
CO5	Sustainable and Strategic Projects	Promote projects that contribute to the EU’s raw materials supply, ensuring they meet high environmental and social standards.
CO6	Monitor Supply Risks	Implement mechanisms to monitor and reduce supply risks, ensuring a stable supply of critical raw materials.
CO7	Environmental Footprint	Require an environmental footprint declaration for all critical raw materials on the market.
CO8	Encourage Resource Efficiency	Promote technological advancements and efficiency to manage and moderate the increase in raw material consumption.

The strategic priorities for the EU battery ecosystem focus on two primary pillars: the technological transition to Lithium Iron Phosphate (LFP) chemistry and the integration of digital sustainability tools. To mitigate the severe geopolitical risks and environmental impacts associated with the extraction of cobalt and nickel, materials characterized by high supply concentration in unstable regions, the study prioritizes a strategic pivot toward LFP battery production. This chemistry utilizes lithium and phosphorus, which are more readily available within European borders, thereby enhancing material sovereignty and reducing reliance on high-risk imports. Additionally, LFP batteries offer a significantly lower environmental footprint and support compliance with EU regulatory standards for responsible sourcing and carbon footprint reduction.

Simultaneously, the framework emphasizes the development of an "integrated sustainability suite" to ensure full transparency and regulatory alignment. This suite merges the Digital Battery Passport (DP) with Life Cycle Assessment (LCA) and eco-design tools to monitor compliance throughout the battery's entire lifecycle. While the implementation of such a system faces challenges regarding data standardization, interoperability, and the need for significant IT investment, it is considered vital for proactive risk mitigation and for achieving the recycling and material recovery targets mandated by Regulation (EU) 2023/1542. Together, these priorities aim to position Europe as a leader in ethically and environmentally responsible battery manufacturing.

Building on the identified vulnerabilities, a set of targeted strategic actions to fortify the EU battery value chain are proposed. A primary recommendation is the accelerated adoption of Lithium Iron Phosphate (LFP) technology, which avoids the use of cobalt and nickel, thereby mitigating geopolitical risks associated with unstable regions and reducing the overall environmental footprint. Furthermore, the immediate investment in domestic resources, particularly geothermal lithium and phosphate deposits are needed, to enhance material sovereignty. To ensure environmental compliance, manufacturing should be prioritized in regions with low-carbon energy mixes. Finally, an "integrated sustainability suite" that merges the Digital Battery Passport (DP) with Life Cycle Assessment (LCA) and eco-design tools is proposed. This technological integration is presented as a vital mechanism for ensuring transparency, enabling circularity, and fulfilling the rigorous requirements of Regulation (EU) 2023/1542.

Global leadership in the battery sector is predicated on proactive investment in domestic resources, the integration of cutting-edge technologies, and a steadfast commitment to sustainability. By leveraging its inherent strengths and mitigating systemic vulnerabilities, the EU can position itself to fulfil its regulatory mandates while defining the global benchmark for ethical and responsible battery manufacturing.

The SWOT analysis presented hereafter provides a final synthesis of the strategic insights derived from the study by Gianvincenzi et al. [9], delineating the critical internal and external factors that shape the execution of the proposed transition pathways.

- ***Internal Strengths & Capabilities:*** The EU's primary advantage lies in its comprehensive legislative ecosystem, which mandates sustainability through the Battery Regulation (EU) 2023/1542 and the CRMA. This is bolstered by untapped domestic resource potentials, particularly geothermal lithium, which offers a lower environmental footprint than traditional mining.

- ***Internal Constraints & Weaknesses:*** Structural vulnerabilities persist due to a lack of immediate raw material self-sufficiency. Even under optimistic scenarios, the internal production and recycling will struggle to meet 2030 thresholds for materials like graphite and cobalt.

- ***External Growth Pathways (Opportunities):*** Technological evolution, specifically the pivot toward LFP chemistries, presents a major opportunity to align the industry with EU-sourced materials (phosphorus and lithium). Furthermore, tools like the Digital Battery Passport could set a global standard for traceability.

- ***External Risks & Challenges (Threats):*** The concentration of supply in geopolitically volatile or dominant markets remains the most significant threat. Additionally, if recycling capacity does not scale at the projected Compound Annual Growth Rate (CAGR), the supply-demand gap will widen.

Evidence from the literature, corroborated by simplified Life Cycle Assessment and regulatory gap analyses, indicates that achieving total material autonomy by 2030 is statistically improbable. Persistent strategic reliance on high-risk jurisdictions remains a challenge, as current recycling efficiencies are insufficient to offset the projected supply-demand imbalance. To address these vulnerabilities, this study proposes a multi-layered strategic framework that leverages Digital Battery Passports and eco-design KPIs to bolster European resilience and ensure strict regulatory compliance.

Acknowledgements

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Development of a Nickel Nanoparticle-Based Electrochemical Sensor for Ciprofloxacin Analysis

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Antibiotics are among the most transformative discoveries of the 20th century, fundamentally altering the clinical management of diverse infectious diseases. Over the eight decades since their discovery, antibiotics have established themselves as the primary pharmaceutical defence against bacterial pathogens [1]. Nevertheless, their escalating consumption has subjected both bacterial communities and broader ecosystems to substantial concentrations of antibiotic residues. This pervasive use across human medicine, veterinary science, and agriculture has resulted in the persistent accumulation of these compounds within environmental and biological matrices [2, 3]. Such environmental residues provide the selective pressure necessary to drive antimicrobial resistance (AMR), posing a significant threat to global public health by rendering standard treatments ineffective. To address this, electrochemical sensors provide an attractive alternative for detection due to their inherent affordability, high temporal resolution, and suitability for field-based analysis. This is particularly relevant for the monitoring of ciprofloxacin (CIP); as a prevalent broad-spectrum fluoroquinolone, its persistence in biological and environmental matrices is a primary factor in the proliferation of antibiotic-resistant bacteria [4, 5].

In this study, a commercially available nickel nanoparticle-modified screen-printed carbon electrode (NiNPs-SPCE; Metrohm DropSens 110D) was utilized as a proof-of-concept platform for the cyclic voltammetric detection of CIP in phosphate-buffered saline (PBS). Using cyclic voltammetry (CV) at a scan rate of 100 mV s^{-1}, the sensor demonstrated a systematic increase in anodic oxidation current across a concentration range of 50–500 µM. A strong linear correlation ($R^2 = 0.99$) was established between the peak current and CIP concentration, yielding a sensitivity of 3.716×10^{-5} mA μM^{-1}. These findings suggest that the NiNPs-SPCE provides a robust, cost-effective solution for rapid ciprofloxacin screening, warranting further investigation in complex biological matrices.

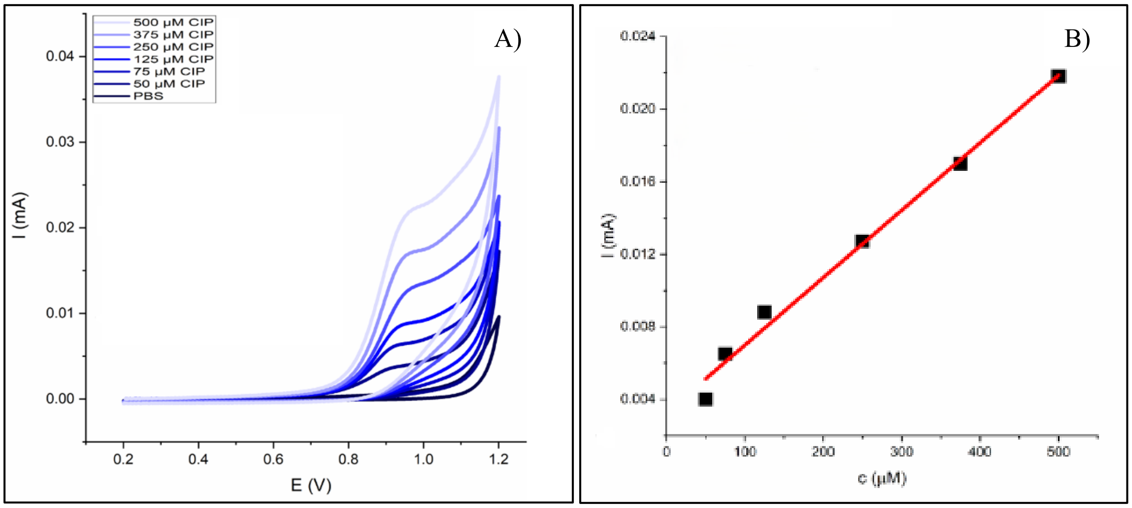

Figure 1 A) Cyclic voltammograms recorded at a nickel nanoparticle–modified screen-printed carbon electrode (NiNPs-SPCE; Metrohm DropSens 110D) in phosphate-buffered saline (PBS) for ciprofloxacin (CIP) concentrations of 50–500 µM (including PBS blank) at a scan rate of 100 mV s^{-1}.
B) Linear calibration plot of the maximum oxidation peak current versus CIP con-centration.

Acknowledgements

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DFT Study of Surface Stability and Electronic Properties of MoP, FeP and CoP for HER

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Introduction

Transition metal phosphides (TMPs), particularly MoP, FeP, and CoP, are widely investigated as promising electrocatalysts for the hydrogen evolution reaction (HER) due to their compositional versatility and favorable electronic properties [1]. As HER is governed by surface-mediated processes, catalytic performance strongly depends on crystallographic orientation and surface electronic structure. Therefore, a systematic analysis of surface facets and their electronic characteristics is essential for the rational design of efficient phosphide-based catalysts [2].

Computational methodology

In this study, density functional theory (DFT) calculations were performed using the Quantum ESPRESSO package. Slab models of MoP, FeP, and CoP corresponding to the (101), (111), (110), and (100) surface orientations were constructed and carefully converged to ensure reliable surface energetics. For each facet, surface energies were evaluated to determine relative thermodynamic stability. The calculated surface energies were subsequently employed to generate Wulff constructions, enabling prediction of equilibrium particle morphologies and identification of dominant exposed facets under thermodynamic conditions.

Surface Characterization

To further characterize the surfaces, total and projected densities of states (DOS) were calculated to analyze the distribution of electronic states in the vicinity of the Fermi level. In addition, electrostatic potential maps were computed to examine surface polarization and variations in the local vacuum potential at the surface–vacuum interface. These analyses provide a comprehensive description of structural stability and electronic properties across different crystallographic terminations.

Outlook for HER Studies

The obtained results will serve as a basis for selecting the most promising and potentially reactive facets for subsequent investigation of hydrogen adsorption energetics and elementary HER steps. A detailed discussion of the computational approach, comparative surface stability, and implications for facet-controlled catalyst design will be presented during the conference.

Acknowledgements

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Highly Sensitive Electrochemical Sensor Based on Gold Nanoparticle for Uric Acid Detection

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The precise and rapid determination of uric acid (UA) in biological fluids is of paramount importance in clinical diagnostics, as it serves as a fundamental biomarker for several metabolic and neurological conditions. Uric acid is the final oxidation product of purine metabolism in the human body, and its abnormal concentration levels in serum and urine are directly associated with pathologies such as hyperuricemia, gout, Lesch-Nyhan syndrome, renal dysfunction, and cardiovascular diseases [1]. Moreover, elevated UA levels are often linked to oxidative stress and inflammatory responses. Despite its clinical significance, the electrochemical detection of UA at conventional electrodes is frequently hindered by high overpotentials, slow electron transfer kinetics, and the presence of interfering substances such as glucose and ascorbic acid [2, 3].

In this work, a robust and portable non-enzymatic electrochemical sensing platform utilizing screen-printed carbon electrodes (SPCE) modified with gold nanoparticles (AuNPs) is presented. SPCEs were chosen as the ideal substrate due to their cost-effectiveness, high reproducibility, and inherent suitability for point-of-care (PoC) diagnostic applications [4]. However, bare carbon surfaces often exhibit poor catalytic activity and are susceptible to surface fouling by protein adsorption in real biological samples. To overcome these limitations, the working electrode surface was functionalized with AuNPs, which provide a high effective surface area, excellent biocompatibility, and superior electrocatalytic properties [5].

The morphological characteristics and elemental composition of the AuNP-modified SPCE were investigated using Scanning Electron Microscopy (SEM) confirming the successful and uniform distribution of gold nanostructures across the carbon matrix. The electrochemical performance of the modified sensor was evaluated using Cyclic Voltammetry (CV) in phosphate-buffered saline (PBS) with addition of 0.1M NaOH (Figure 1).

The experimental results demonstrate that the integration of AuNPs significantly enhances the oxidation current of uric acid compared to unmodified electrodes. Based on the literature, the sensing mechanism is driven by the high affinity of the gold surface toward UA molecules, facilitating a rapid two-electron and two-proton transfer process [6]. This electrocatalytic enhancement allows for the detection of UA at lower oxidation potentials, thereby reducing the influence of common co-existing interferents. Analytical characterization revealed a wide linear dynamic range (from 1.0 µM to 10 mM), covering the typical physiological concentrations found in human biofluids [7]. The sensor achieved a remarkably low limit of detection (LOD) and demonstrated high sensitivity of 40 µA/mM.

In conclusion, this research provides a scalable and efficient strategy for the fabrication of disposable non-enzymatic UA sensors. By combining the benefits of screen-printing technology with the exceptional catalytic performance of gold nanoparticles. This platform holds significant potential for the next generation of wearable and handheld devices, contributing to more accessible and effective personalized healthcare management [8].

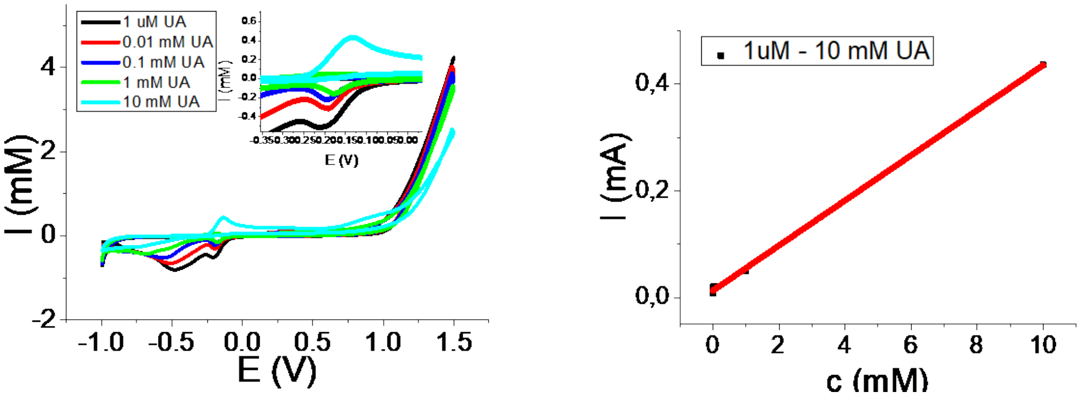

Figure 1 Cyclic voltammograms for various UA concentrations in 0.1 M NaOH in PBS (left), dependence of current response on concentration of UA (right).

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Optimization of CuO 550 Amount on SPCE Electrodes for Enhanced Electrochemical Detection of Insulin

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Diseases such as Diabetes mellitus, insulinomas, or other metabolic disorders are associated with abnormal concentrations of the small polypeptide hormone insulin in the human body. Accurate determination of insulin levels is therefore essential for clinical diagnostics and metabolic monitoring [1, 2]. In recent years, electrochemical sensing platforms based on screen-printed carbon electrodes (SPCEs) have attracted significant attention due to their low cost, disposability, ease of surface modification, and compatibility with portable analytical systems [3].

One of the most effective strategies for enhancing sensor performance involves surface modification with metal or metal oxide nanomaterials. Cu(II) ions can interact with specific amino acids present in the insulin molecule through interactions, thereby improving electrochemical detection. Copper(II) oxide (CuO), therefore, represents a promising modification material for insulin sensing applications [4].

This work focuses on SPCEs modified with copper oxide fibers synthesized from recycled materials. Screen-printed carbon electrodes (SPCE 11L, DropSens, Metrohm) were modified by drop casting a dispersion of CuO 550/MWCNTs. The CuO 550 fibers (Figure 1) were synthesized through a recycling process in collaboration with researchers from the Slovak Academy of Sciences (SAS). To evaluate the effect of CuO amount, three types of modified electrodes were prepared containing 0.0715 g, 0.10 g, and 0.12 g of CuO 550.

The modified electrodes were then used to investigate the electrochemical response of insulin oxidation using cyclic voltammetry (CV).

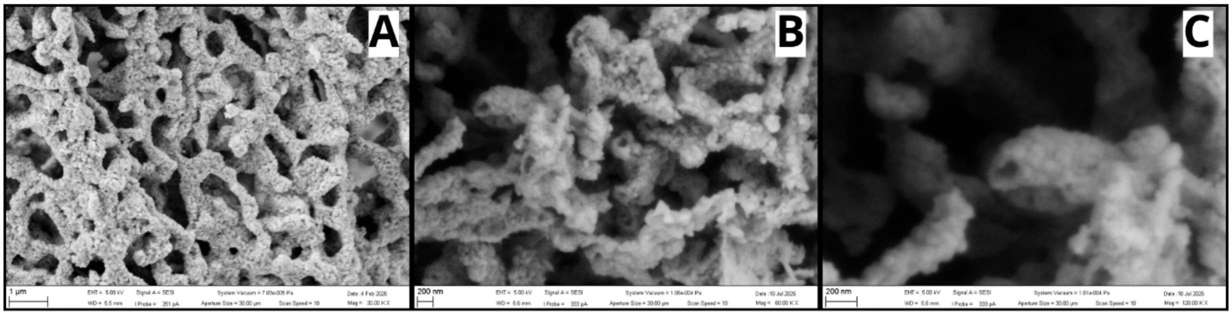

Figure 6 SEM images of CuO 550 fibers at magnification 30.000x (A), 60.000x (B), and 120.000x (C).

Results shown in Figure 2 indicate that the current response of the modified electrodes increased progressively with increasing CuO 550 amount. This trend demonstrates that higher amounts of CuO enhance the electroactive surface area and facilitate electron transfer at the electrode interface. These findings highlight the critical role of CuO amount in optimizing the sensitivity and analytical performance of SPCE-based insulin sensors.

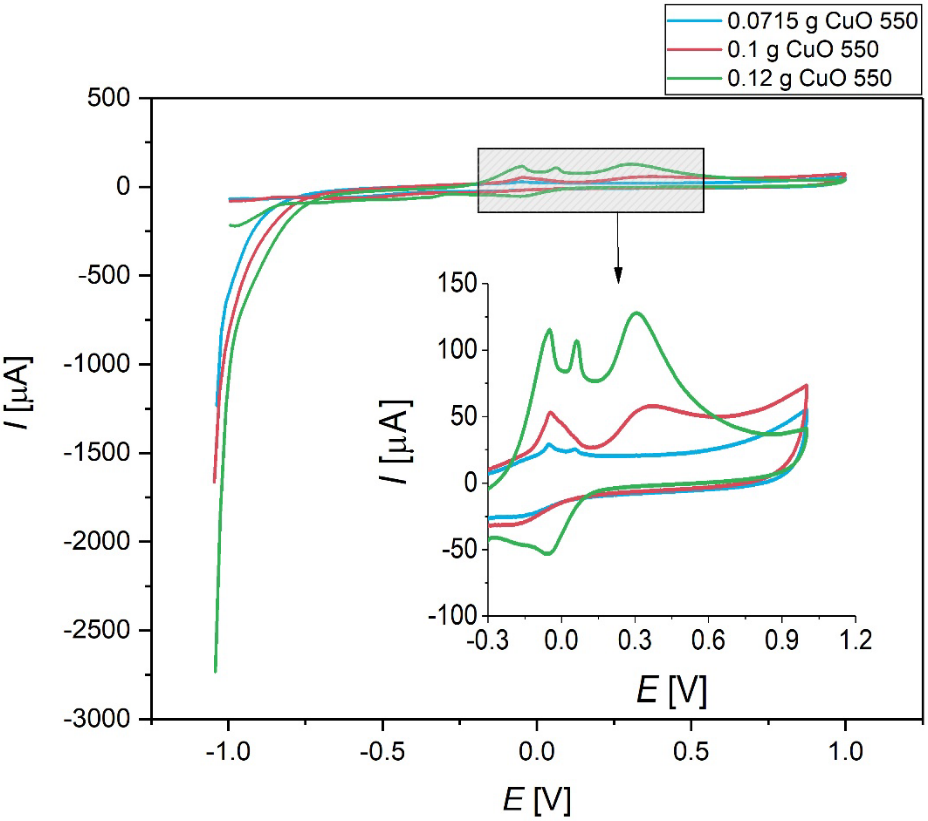

Figure 7 Cyclic voltammetry in 10 µM insulin in PBS (pH=7) on SPCE electrodes modified with MWCNTs and various amounts of CuO 550 fibers at a scan rate of 100 mV.s^{-1}.

SPCE electrodes modified with CuO 550/MWCNTs demonstrated a clear and measurable electrochemical response toward insulin oxidation. The current response increased progressively with higher CuO amounts, highlighting the importance of optimizing the amount of CuO for enhanced sensor performance. Among the tested electrodes, the one containing 0.12 g of CuO exhibited the highest current response. These findings suggest that controlled CuO amount is a key factor in designing sensitive and reliable SPCE-based sensors for insulin determination. The approach also illustrates the potential of using recycled CuO materials for developing cost-effective and environmentally friendly electrochemical biosensors.

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Enhancing Bone Cement Structure via Modified Polyol-Citrate Polyester Incorporation

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Introduction

Bone cements represent an important class of bone substitute biomaterials, formed by mixing powder and liquid components into a moldable paste that solidifies after implantation and provides structural support at the site of application [1]. Currently, several types of cementitious materials are used in regenerative medicine, such as non-degradable polymeric acrylic cements (e.g., PMMA) and biodegradable cements, for example calcium sulfates (CSs), calcium silicates (CaSis), and phosphate-based cements like calcium phosphates (CaPs) and magnesium phosphates (MgPs). These materials have a wide range of applications, including reconstruction of bone defects, fracture stabilization, and fixation or anchoring of implants [1,2].

Among them, CaPs, MgPs, and combined calcium–magnesium phosphate systems (CMPs) have attracted particular attention due to their excellent biocompatibility, biodegradability, and osteoconductive properties [3]. Incorporation of Mg^{2+} ions into CaP-based systems has been reported to enhance osteoblast activity and support bone remodeling [4]. Conventional MgP cements, typically formulated from magnesium oxide (MgO) and potassium dihydrogen phosphate (KH_2PO_4), are often associated with rapid setting reactions, heat release during setting, and elevated alkalinity caused by MgO hydration, which may limit their clinical handling and biological performance. Consequently, various strategies have been explored to address these limitations, including the use of setting retarders and modification of reactant composition and reactivity. Most reported strategies to improve MgP cements focus on reducing the reactivity of MgO powders, for example by annealing at high temperatures (>1500 °C), which leads to particle coarsening and consequently slower reaction kinetics. An alternative approach involves modifying the reactivity of the phosphate component.

In this study, a less reactive calcium phosphate phase based on hydrogen phosphate (HPO_4^{2-}), represented by brushite, was employed instead of highly reactive dihydrogen phosphates to tailor the setting behavior of CaMgP cements. In parallel, numerous studies have demonstrated that incorporation of polymeric phases, either within the liquid component or as part of the powder mixture, can beneficially influence the setting characteristics, mechanical performance, and biological response of bone cements. In our previous work [5], incorporation of a polyol-based glycerol–citric acid polyester into hydroxyapatite CaP cement significantly improved the overall mechanical performance, including compressive, diametral tensile, and flexural strength. This enhancement was attributed to the formation of a thin, homogeneous polyester coating on cement particles, leading to a denser and less porous microstructure, improved interparticle bonding, and additional hydrogen bonding between residual carboxyl groups of the polymer and surface phosphate groups of the cement matrix. In our more recent work [6], the GCA polyester was further functionalized with bioactive tannic acid and boric acid, both acting as effective crosslinking agents, with the aim of stabilizing and tuning the native polymer network. Tannic acid is additionally known for its diverse beneficial biological properties and strong chelating ability toward multivalent ions. Based on these characteristics and our previous findings with polyester-modified CaP cements, we hypothesize that incorporation of the modified GCA/TB system into CMP cements may positively influence overall cement performance. In particular, the chelating capability of tannic acid is expected to interact with available Ca^{2+} and Mg^{2+} ions, potentially moderating the rapid setting behavior typical of MgO-based formulations. The present work therefore investigates the effect of GCA/TB incorporation on the microstructure, setting behavior, and compressive strength of CMP bone cements.

Results

The CMP cement powder was prepared by mechanical milling of MgO and $CaHPO_4$ powders mixed in a 1:3 weight ratio. The powders were milled in a planetary ball mill (Pulverisette 5, Fritsch, Germany) using an agate vessel and three agate balls at a rotational speed of 730 rpm. Milling was performed in two cycles of 15 min. Three cement formulations were produced by mixing the CMP powder with either distilled water (CMP0) or aqueous solutions containing 2 and 5 wt% dissolved GCA/TB polyester (CMP2 and CMP5). Cement pastes were prepared by manual mixing in an agate mortar at an optimized powder-to-liquid ratio, followed by casting into cylindrical stainless steel molds to obtain specimens 6 mm in diameter and 12 mm in height. The samples were immediately stored at 37 °C under 100% relative humidity for 30 min and subsequently immersed in simulated body fluid (SBF) for 24 h prior to characterization.

Final setting time measurements performed using a Vicat needle (400 g load, 50 mm needle) confirmed the beneficial effect of GCA/TB incorporation into CMP cements. The pure CMP formulation exhibited a rapid final setting time of approximately 5 min, which increased to 12 and 33 min after addition of 2 and 5 wt% GCA/TB polyester to the liquid phase, respectively. This prolongation may be attributed, at least in part, to chelation of Ca^{2+} and Mg^{2+} ions by tannic acid, together with the presence of the polymeric network, which slows dissolution–precipitation reactions during cement setting. However, excessive polyester content (5 wt%) resulted in overly delayed hardening, indicating that lower concentrations represent a more suitable compositional window for practical applications.

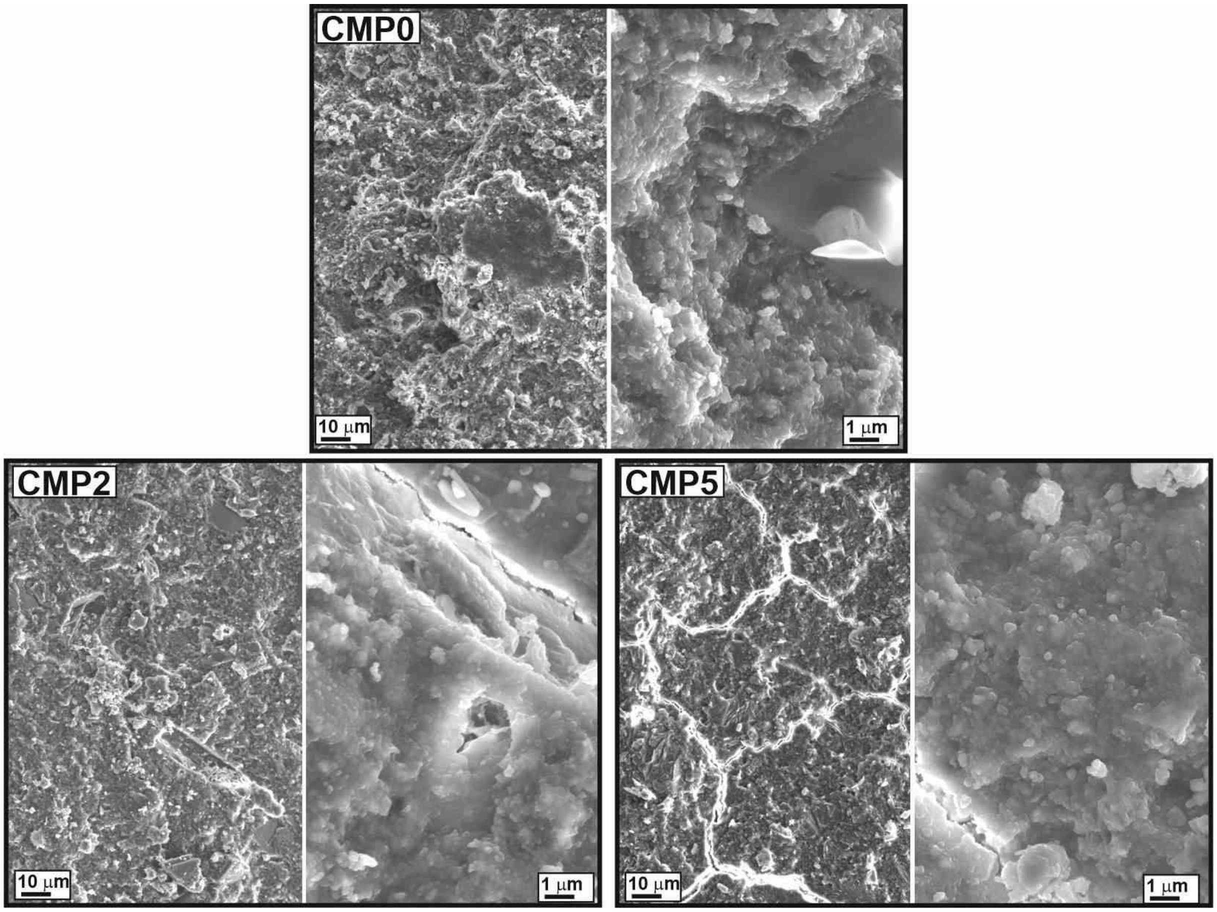

Figure 1 SEM microstructure of fractured cement surfaces after 1 day setting in SBF solution.

SEM micrographs of fractured surfaces after 1 day of hardening in SBF (Figure 1) reveal pronounced microstructural differences between the studied cements. The neat CMP sample exhibits a heterogeneous structure composed of agglomerates of fine globular particles (~200–300 nm) surrounded with larger angular brushite crystals exceeding 50 μm. Numerous micro and macropores with sizes ranging from approximately 1 to 10 μm are also visible, indicating a relatively porous fracture morphology. In contrast, CMP2 and CMP5 composites display denser and more compact microstructures with a reduced pore fraction. The cement particles appear partially embedded in a thin polymeric matrix, suggesting the formation of a continuous polyester film that becomes more pronounced at higher (5 wt%)

GCA/TB content. Localized angular voids and pull-out features corresponding to detached brushite crystals are occasionally observed, consistent with fracture occurring at particle–matrix interfaces.

These microstructural changes were reflected in the mechanical performance of the cement systems (Figure 2). After 1 day of hardening in SBF, the neat CMP exhibited a compressive strength of 23 ± 4 MPa. Incorporation of an optimal 2 wt% GCA/TB significantly increased the strength to 55 ± 6 MPa, whereas further increasing the polyester content to 5 wt% reduced the strength to approximately 33 MPa. The strength enhancement at lower polyester content is associated with microstructural densification and improved interparticle bonding promoted by the polymeric phase. In contrast, excessive polymer addition likely interferes with cement matrix continuity and crystal interlocking, leading to a partial reduction in load-bearing capacity.

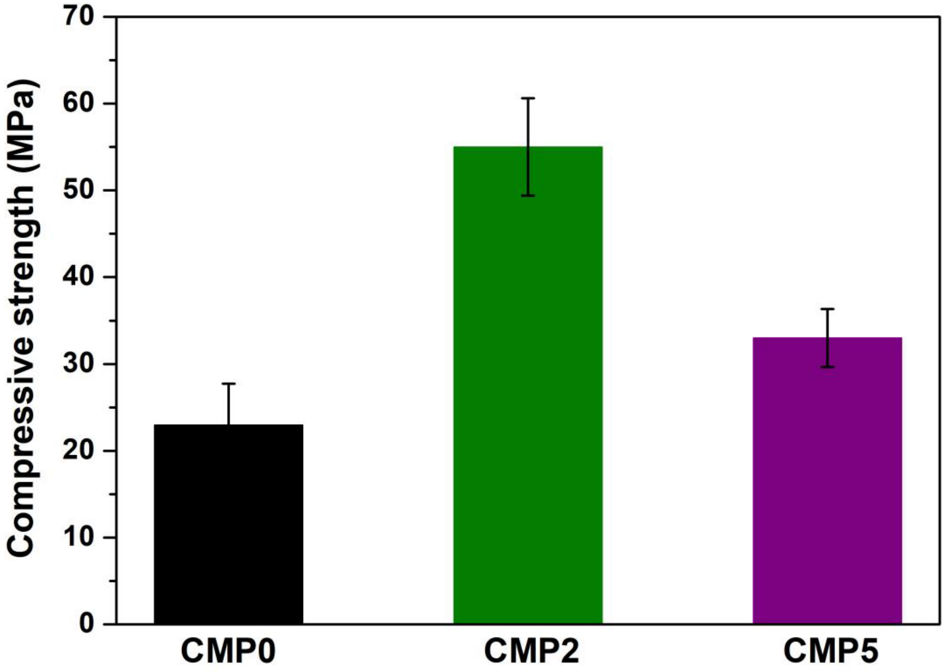

Figure 2 Compressive strength of the CMP cements after 1 day setting in SBF solution.

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Spherical Powder Particles based on Transition Metal Phosphides for Enhanced Hydrogen Evolution Reaction

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Rising global energy demand, driven by population growth, urbanization, industrialization, and technological development, is expected to continue growing, potentially doubling by 2050. Reliance on fossil fuels poses environmental and health risks, and their extraction is becoming increasingly challenging and costly. Hydrogen offers an efficient energy carrier and storage solution, enabling long-term, large-scale storage of excess renewable energy via electrolysis with minimal energy loss. Electrochemical water splitting, a non-spontaneous process, involves two half-reactions: the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER).

Electrolysis technologies include Alkaline Water Electrolysis (AWE), Anion Exchange Membrane (AEM), Proton Exchange Membrane (PEM), and Solid Oxide Electrolysis (SOEC). AWE is the most mature, cost-effective, and widely deployed method for large-scale hydrogen production, but it suffers from low operational flexibility and poor efficiency at low current densities. Research focuses on improving performance using advanced electrode materials with optimized composition, morphology, and nanostructure to reduce overpotential and enhance stability and kinetics.

This study presents a scalable, cost-effective, and user-friendly approach for the preparation of spherical transition metal phosphide (TMP) powders, including MoFeP, MoFeNiP, and MoFeCoP. Hollow spherical precursor particles were produced via a facile spray drying method and subsequently converted into phosphides through heat treatment at 650 °C in a reducing atmosphere. The resulting 3D-structured spheres were evaluated as catalysts for the hydrogen evolution reaction (HER) in alkaline water electrolysis. Among the synthesized catalysts, MoFeCoP exhibited superior HER performance, achieving an overpotential of η_{-10} = 285 mV at -10 mA cm^{-2}, outperforming MoFeP ($\eta_{-10} \approx$ 337 mV) and MoFeNiP ($\eta_{-10} \approx$ 421 mV). Tafel analysis indicated a Volmer-Heyrovsky mechanism with the Heyrovsky step as rate-determining, while electrochemical measurements revealed enhanced active surface area and reduced charge transfer resistance for MoFeCoP. Chronoamperometry demonstrated stable operation over 22 h at -385 mV vs RHE. These results highlight Co-doped TMPs as efficient, stable, and low-cost electrocatalysts for alkaline water splitting, offering a versatile platform for large-scale hydrogen production and future catalyst design beyond noble-metal systems.

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Electrochemical Detection of Insulin at Neutral pH Using Ni Nanoparticle-Modified Screen-Printed Carbon Electrodes

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Insulin is a polypeptide hormone produced by pancreatic β-cells and plays a central role in glucose metabolism and energy homeostasis. Abnormal insulin secretion or impaired insulin action is directly associated with metabolic disorders, particularly diabetes mellitus, which represents one of the most prevalent chronic diseases worldwide. Accurate and rapid determination of insulin levels in biological fluids is therefore crucial for early diagnosis, therapy monitoring, and fundamental biomedical research [1].

Conventional methods for insulin determination, such as enzyme-linked immunosorbent assays (ELISA), radioimmunoassays, and chromatographic techniques, provide high sensitivity and selectivity [2]. However, these approaches are often time-consuming, require expensive instrumentation, complex sample preparation, and trained personnel. In recent years, electrochemical sensing has emerged as an attractive alternative due to its inherent advantages, including high sensitivity, short analysis time, low cost, portability, and compatibility with miniaturized and point-of-care devices [3].

Screen-printed electrodes (SPEs) represent a particularly promising platform for electrochemical biosensing. They are disposable, mass-producible, and require only small sample volumes. Nevertheless, the direct electrochemical detection of insulin at bare carbon electrodes is limited by sluggish electron transfer kinetics and relatively low sensitivity, especially under physiological pH conditions. Therefore, surface modification strategies are essential to enhance the electrochemical response [4].

Nanostructured materials, particularly metal nanoparticles, have been extensively investigated to improve electrode performance. Nickel nanoparticles (NiNPs) are of particular interest due to their good electrical conductivity, electrocatalytic activity, chemical stability, and relatively low cost compared to noble metals. Nickel-based materials exhibit favourable redox properties and can significantly enhance electron transfer processes, thereby improving sensitivity toward biomolecules [5].

Most previously reported electrochemical studies on insulin detection were performed under strongly alkaline conditions, where nickel hydroxide/oxyhydroxide redox couples facilitate electrocatalytic oxidation [6]. However, such conditions are not compatible with real biological samples and may lead to protein denaturation. Therefore, the development of electrochemical sensors capable of operating at neutral pH is highly desirable for practical biomedical applications.

In this study, carbon screen-printed electrodes (SPCE) were modified with electrodeposited nickel nanoparticles to develop a sensitive electrochemical sensor for insulin detection at physiological pH (7.4). The influence of surface modification on electrochemical behaviour was investigated, and the analytical performance of the developed sensor was evaluated in terms of sensitivity, linear range, detection limit, repeatability, and applicability to model biological samples. Before analytical measurements, the electrode surface was electrochemically activated by cyclic voltammetric pre-cycling within the potential window of −1.0 V to +1.0 V for 10 cycles. This activation procedure promoted surface stabilization and enhanced electrocatalytic performance. Subsequently, insulin could be determined under physiological pH conditions, and the developed sensor was successfully applied to human serum samples. The electrode surface morphology was investigated using microscopic techniques. Based on calculations using the Randles–Ševčík equation, a 1.15-fold increase in the electroactive surface area was observed for the NiNP-modified electrode compared to the bare electrode. In addition, the NiNP-modified SPCE exhibited improved analytical performance, characterized by a correlation coefficient (*R^2*) of 0.99, a sensitivity of 4.71×10^{-5} A·µM^{-1}, and a limit of detection (LOD) of 1 µM.

Based on the obtained results the developed electrochemical platform represents a simple, cost-effective, and promising approach for insulin detection under physiologically relevant conditions, with potential for further optimization toward point-of-care diagnostic systems**.**

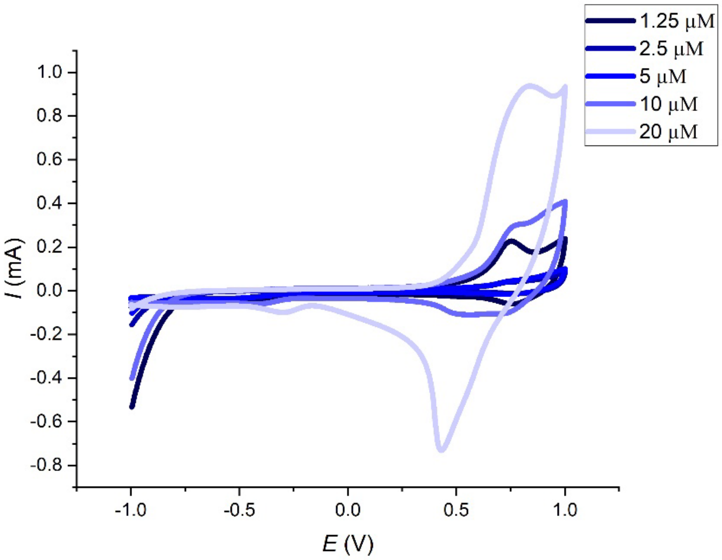

Figure 1 Cyclic votlammograms of various insulin concentrations at NiNPs modified SPCE at scan rate of 100 mv/s.

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Energy Storage Systems

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The rapid expansion of global industries and the growing population have significantly increased energy demand, highlighting the fundamental limitations of traditional fossil fuels and emphasising the urgent need for sustainable, clean, and abundant energy alternatives. Storage systems for environmentally friendly energy are essential for mitigating the intermittency of renewable sources and ensuring a stable power supply by capturing surplus generation for later use [1]. The scheme in Figure 1 outlines a comprehensive process for capturing and storing energy derived from renewable sources, enabling its utilization at a later time.

Figure 1 Scheme for capturing and storing energy from renewable sources, enabling its use at a later time.

Classification of Energy Storage Systems

Energy storage systems are primarily divided into three main categories: mechanical, electrochemical, and thermal. These categories can be further detailed based on the nature of the stored energy, the underlying technology, intended applications, and capacity. Such classifications generally result in four major types: mechanical, chemical, electrochemical, and thermal energy storage [2].

Mechanical energy storage includes technologies such as pumped hydroelectric storage, compressed air energy storage, and flywheels. These systems store energy through physical displacement or kinetic motion rather than chemical changes [2].

Chemical energy storage, on the other hand, depends on the transformation of energy via chemical bonds, often involving fuels like hydrogen or synthetic hydrocarbons. Conversely, electrochemical energy storage systems operate through reversible redox reactions to directly convert chemical energy into electrical energy [3,4]. While chemical storage mainly relies on fuels such as coal, petrol, or hydrogen to produce power, electrochemical systems focus on the internal conversion of energy within a cell [5].

Electrochemical systems store energy through reversible reactions that enable the conversion between chemical and electrical states [5]. These devices use a potential difference between two electrodes to drive electron flow through an external circuit while ions migrate internally through an electrolyte [2]. Their operation relies on the thermodynamic properties of the active materials, where cell voltage results from the chemical potential difference between oxidised and reduced species [6,7]. These devices are mainly classified as rechargeable batteries (e.g., lithium-ion, lead-acid, sodium-sulfur) and electrochemical capacitors (e.g., supercapacitors or hybrid capacitors) [2]. The lead-acid battery is one of the oldest and most established rechargeable storage technologies. It employs a sulphuric acid electrolyte with lead dioxide and sponge lead as the positive and negative electrodes, respectively. During discharge, the sponge lead at the anode oxidises to lead sulphate whilst releasing electrons, whereas the lead dioxide at the cathode is reduced to lead sulphate. This reversible reaction restores the original active materials upon charging [8]. Lithium-ion batteries operate via the reversible intercalation of lithium ions between a graphite anode and a metal oxide cathode - typically made of lithium cobalt oxide or lithium iron phosphate - separated by an organic electrolyte and a porous polymer membrane [9]. Their rapid charge/discharge cycles, lightweight design, and high efficiency (up to 90%) have made them the most widely used type of battery, ranging from small-scale consumer electronics to large-scale applications such as electric vehicle batteries. Sodium-sulfur batteries operate at high temperatures, usually between 300°C and 350°C. They use molten sodium as the anode and molten sulphur as the cathode, separated by a solid beta-alumina ceramic electrolyte that facilitates sodium ion conduction [11]. During discharge, sodium atoms oxidise at the anode to release electrons and sodium ions; these ions migrate through the ceramic electrolyte to the cathode to form sodium polysulfides. This process is reversed during charging to recreate metallic sodium and sulphur. Electrochemical capacitors, or supercapacitors, are classified into electric double-layer capacitors (EDLC) and pseudocapacitors. Both employ electrodes immersed in an aqueous or ionic liquid electrolyte to store energy. In EDLCs, energy is stored via electrostatic charge separation at the electrode-electrolyte interface without chemical reactions. Conversely, pseudocapacitors use fast surface redox reactions to attain higher energy density whilst maintaining high power. The core mechanism of these devices relies on the reversible movement of ions between the cathode and anode, driven by an external electron flow [12].

Thermal energy storage systems capture and retain energy by altering the temperature of a storage medium, such as water, molten salts, or phase-change materials. This energy is later recovered through heat-exchange processes to provide heating, cooling, or power generation as needed [1].

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