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Book of Abstracts

Sanja POTRČ Miloš BOGATAJ Zdravko KRAVANJA Zorka NOVAK PINTARIČ
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Emerging Technologies and Innovative Approaches – from Development Environments to Practical Implementation

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7TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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Numerical Simulation of Anaerobic Digestion Process in Bioreactors: Biomodel Calibration

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One of very effective and environment-friendly waste-to-energy technologies is anaerobic digestion (AD). Till now, various more or less complex mechanistically inspired mathematical models for AD process simulation have been developed (Flores-Alsina et al, 2016; Liu et al, 2022; Sun et al, 2021). In these models, the number of model parameters increases with the complexity of the model. Since these parameters are typically unknown, various procedures for their calibration were developed. Commonly, researchers calibrate only the most important model parameters, while some estimated values available from the literature are used for the less important parameters. By this simplification, the interactions of the most and less important parameters are neglected. In order to highlight the benefits gained by the calibration of all model parameters, this paper deals with numerical simulation of the AD process by using a very complex BioModel. For this purpose, various perturbations of all model parameters are investigated and analyzed. The self-

developed complex BioModel takes into account chemical, biochemical, and physicochemical process as well as the activities of various commercial biological and inorganic additives (Kegl, 2022). The degradations of carbohydrates, proteins, and lipids through many intermediates into the final products are described by 80 ordinary differential equations and 54 algebraic equations (Kegl, 2022). The developed BioModel contains 187 model parameters, which have to be calibrated. For this reason, a special active set optimization procedure was developed, which takes into account the interactions of all model parameters (Kegl & Kovač Kralj, 2022). The optimization procedure proposed in this work is based on the assumption that uniqueness-related problems can be mitigated at least to some extent by performing gradual optimization of AD parameters (Kegl & Kovač Kralj, 2020). This procedure involves a sensitivity analysis, the BioModel, and a gradient-based optimization method with an adaptive approximation scheme. The model parameters are calibrated with respect to the measured AD performance in two continuously stirred tank bioreactors of a full-scale biogas plant in a period of one year. The AD performances measured in a period of another year are used to validate the model by using the calibrated model parameters. The importance of the accuracy of the calibrated BioModel parameters was investigated by an extra study. In this study, the influence of various perturbations of model parameters on the accuracy of AD performance prediction is evaluated. A comparison of the simulated AD performances with experimental data clearly shows that the disagreement increases by increasing the perturbations. The obtained results confirm the importance of accurate calibration of all BioModel parameters.

Keywords: Anaerobic digestion, BioModel, Active set optimization procedure, Sensitivity analysis, Gradient-based method, Perturbation of calibrated model parameters

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Energy System Optimization of a Future Deployable Defence Camp

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In recent years, renewable energy has received significant attention due to the commitment to reduce the carbon footprint, a goal recently introduced by the European Union through the Green Deal (European Commission, 2019) and later supplemented by the Fit for 55 package (European Commission, 2021). Additionally, the aim is to reduce the EU's dependency on the import of fossil fuels, which is the main objective of the Repower EU plan (European Commission, 2022), designed as a response to the EU's high past dependency on Russian natural gas.

To address the dual challenges of cutting greenhouse gas emissions and securing a stable energy supply, a shift from fossil fuels to renewable energy is needed. One effective strategy to achieve greater integration of renewable energy into power systems is through the development of smart microgrids. These grids act as energy hubs, utilizing renewable energy sources to enhance efficiency and resilience. Although such an approach can lead to a significant reduction in emission of greenhouse gases, in some applications, such as in the defence sector, the robustness of the energy system must be prioritized in certain crisis situations.

To address the above-mentioned challenges and opportunities, this study analyses the potential of integrating renewable energy sources into the defence sector, specifically deployable defence camps, which can operate in a wide range of climatic conditions. The primary goal was to develop a methodology for defining an energy system that achieves the following objectives:

- Reduction of CO_2 emissions;
- Increase of renewable energy sources;
- Decrease of energy imports from external sources;
- Ensuring autonomous operation.

The design of the energy microgrid topology for deployable camps in 2030 and 2050 scenarios fulfilling the objectives outlined above followed a systematic three-step procedure:

1. Selection of technologies based on evaluation of key performance indicators and integration of various renewable energy related production and storage technologies;
2. Determination of functional zones within the deployable camp based on camp characteristics and energy consumption load profiles;
3. Distribution of energy components within various functional zones to address specific defence performance requirements such as autonomous operation, safety, resilience and interoperability

In the next phase, the designed energy systems for 2030 and 2050 scenarios, consisting of various energy conversion, storage, and management components, were used in an optimization procedure. This procedure aimed to minimize costs while considering various technology and operation-related constraints to determine the optimal sizing and operating characteristics of the energy system.

The performance of the optimized energy systems was compared to the legacy scenario, which comprises currently employed energy technologies in defence applications. This comparison was made to evaluate the reduction in CO_2 emissions, the increase in the share of renewable energy sources, and the decrease in energy imports from external sources achieved by the optimized systems.

Keywords: simulation of energy microgrid, sustainability, energy efficiency, renewable energy, deployable defence camp, cost minimization, microgrid topology optimization

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Use of Green Solvents in Hydrothermal Carbonization of Biomass

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Hydrothermal carbonization (HTC) is a thermo-chemical process in which biomass is converted into hydrochar in the presence of a liquid medium, usually water. The process is usually carried out at temperatures between 180 and 250 °C, whereby the so-called process liquid is produced in addition to the main product hydrochar. The hydrochar obtained has improved chemical properties and can be used for a variety of purposes, including as a solid fuel or adsorbent, and the process liquid, which is rich in organic compounds and nutrients, can be used to extract valuable components. (Zhi et al., 2024)

Instead of water, various other liquids can be used in the HTC process, as the carbonization of biomass and the extraction of valuable components can be improved by the addition of acids, bases and many other solvents. In particular,

green solvents such as deep eutectic solvents (DES) have gained attention in recent years to improve the sustainability and economics of HTC (Li et al., 2023).

DES consists of at least two components, one of which acts as a hydrogen bond donor and the other as a hydrogen bond acceptor. Deep eutectic solvents have good chemical and physical properties and are relatively inexpensive solvents that have attracted attention mainly because of their outstanding properties, including high solubility and conductivity and low toxicity (Álvarez et al., 2023). They can also be easily synthesized and are widely used as an environmentally friendly alternative to conventional organic solvents.

The aim of this study was to analyze and compare the products formed during hydrothermal carbonization with the selected DES solvent with those formed during conventional hydrothermal carbonization in an aqueous medium. For this purpose, two HTC tests were carried out with a biomass sample under selected operating conditions and the products obtained were characterized with regard to various chemical-physical parameters.

Keywords: hydrothermal carbonization, green solvent, lignocellulosic biomass, hydrochar, characterization

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Power-To-Methanol Production From Green Hydrogen and Captured CO_2

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The aim of this study was to simulate the synthesis of methanol using green hydrogen. Methanol is easier to handle and serves as a raw material in various chemical processes. Its production also requires CO_2, which was assumed to be captured using the monoethanolamine (MEA) absorption process, a widely used technology for capturing CO_2 from industrial flue gases. It was assumed that the hydrogen needed for methanol synthesis was obtained through alkaline water electrolysis, one of the most common technologies for hydrogen production using renewable energy sources. The captured CO_2 and produced H_2 were then converted into methanol through CO_2 hydrogenation, using either a direct or two-step synthesis method. In the direct method, CO_2 was directly hydrogenated to methanol. In the two-step method, CO_2 was first converted to CO via the Reverse Water–Gas Shift reaction, and then to methanol.

In addition to simulating the process, we also analyzed utility consumption and costs, as well as performed a sensitivity analysis with respect to reactor temperature and hydrogen inlet flow. The results showed that direct synthesis yields 1.4% more methanol compared to the two-step synthesis. Direct synthesis consumes 2.33 MWh/t of methanol, whereas two-step synthesis consumes 2.79 MWh/t of methanol. This difference corresponds to an annual savings potential of 2.2 million dollars.

Keywords: Power-to-X, Aspen Plus, methanol, CO_2 capture, methanol production, water electrolysis

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Energy Implications of Circular Economy Solutions and Renewable Energy Integration

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While the current World situation is characterised by increased geopolitical tensions, the environmental and sustainability issues have not disappeared. Moreover, the radical improvement of resource-saving and emission reduction is an objective inherently aligned with the objectives of increased resilience and energy/resource security. In this context, Széchenyi István University has launched an ambitious research programme dedicated to sustainability in a variety of domains, including fundamental science, engineering, supply chains, business processes, and social science. Within these, the Circular Economy and the integration of renewable sources into the energy supply to the economy are important areas related to each other, with the potential to minimise resource demands and emissions to a sufficient degree.

This presentation is aiming to overview key developments in the mentioned areas, mapping them into a coherent vision for integrated symbiosis networks that minimise the need for fresh resources without compromising the level and pace of

economic development and preserving the resilience of regional economies. The core developments centre around two concepts – (a) Process Integration and (b) Process Network Synthesis and Optimisation. The former is a family of methods for minimising resource intake while maximising recovery and reuse. The latter is a sub-area of Process Synthesis exploiting the powerful P-graph framework for optimising structurally complex networks.

The overview is followed by analysis and discussion, showing the high importance of energy and exploiting energy integration as a fundamental binding element of diverse activities in society and economy. This is leading to an integrated vision for energy recovery, reuse, and cascading via optimal integration, with the goal of achieving higher rates of circularity in the Circular Economy and maximising renewable energy share with actual emission reduction.

Keywords: circular economy, renewable energy, energy integartion, process synthesis, sustainability

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Waste Converting Into Products

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The usage of the fossil has a negative effect on the environment. Waste, such as Municipal solid waste (MSW), is possible resource for chemical and energy productions, which can be reduce the dependence on natural gas. This applied study presents the technique, which is based on the reusage of different MSW, supported by the mathematical model and the Aspen Plus® simulator for syngas converted into different products: methanol, ethanol, synthetic gasoline etc. The mathematical model includes real-simulated results. Gassed MSW and the purified circulated flue gas can enter as complete circular economy systems into reforming for syngas (as components of CO, CO_2, H_2, H_2O) production. The further different products, such as methanol, ethanol and/or synthetic gasoline, are depending on the critical molar flow rate of CO and CO_2. The molar flow rate of hydrogen is generated in surplus, therefore hydrogen can be cleaned and produced as co-product.

Methanol, ethanol and/or synthetic gasoline produce by the catalytic hydrogenation of carbon monoxide and carbon dioxide within the exothermic reactor with the calculated conversions dependent on the operation conditions. The alternatives include the individual or mixture of the different products production from MSW, including the garbage and CO_2 emission reductions.

Keywords: waste, flue gas, syngas, methanol, ethanol, fuel

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Will 3D Printing Shape the Future of Industry?

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The motivation for the paper on Additive Manufacturing (AM) stems from its potential to promote technological, social and environmental progress. With the advancement of this technology, we can tackle pressing global challenges and pave the way for a more innovative and sustainable future. AM or 3D printing has gained importance in Industry 4.0, which is transforming traditional manufacturing with digital technologies, data analytics, and automation. This shift leverages advances such as IoT, artificial intelligence, cloud computing, robotics, and AM to transform product design, manufacturing, and distribution. That is why AM is currently still in a phase of rapid development and offers us many challenges.

Conventional manufacturing often uses "non-green" materials, consumes large amounts of energy for both manufacturing and for warehouses, and transports, emits significant amounts of carbon through the "cradle to grave" life cycle process, and creates momentous amounts of waste, which are not fully covered by recycling processes. In contrast, AM assembles products layer by layer, reducing raw material, waste, and energy consumption, and promoting resource efficiency, providing a

sustainable alternative that considers the entire life cycle, from environmental design to recycling.

However, AM has still many challenges and open questions, which mainly relate to the safety of the process, use, legislative regulations, and the quality of the material. Material selection has a significant impact on the quality of AM processes and consequently on quality of final products, as different materials have different properties that affect performance and durability. The balance between quality and cost-effectiveness and the reduction of the carbon footprint of transport through localized production are also of key importance. AM is revolutionizing production, healthcare and everyday life. Its uses range from life-saving medical implants to sustainable building materials with significant environmental benefits. Besides, even rockets were already printed and tested, implying a huge overall potential of the technology. Therefore, a review of the literature on state-of-the-art and scientific articles and an analysis of current challenges is extremely important and can significantly help us in the planning and success of further research.

Keywords: Additive Manufacturing, LCA, LCCA, Cons, Pros and Bottlenecks, Greener economy

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Measuring Circularity: A Top-Down Approach to Driving Circular Economy Transition

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Effective monitoring of countries' and companies' progress towards a circular economy requires an integrated, quantitative monitoring framework harmonized across macro (countries) and micro (companies) levels. This project adapts a methodology originally developed for companies (Baratsas et al., 2022) to a macro-level by utilizing Eurostat and national database data. The focus is on collecting data in key circular economy areas: waste, water, raw materials, packaging, energy, and emissions. Values are normalized on a scale of 0 to 100, with 0 representing a linear economy and 100 indicating a fully circular one. Weighted averages of these values are calculated to create sub-indices for each category, which are then combined into an overall circularity index for the country or company. This approach enables the monitoring of specific areas as well as overall progress towards circularity.

This paper demonstrates a top-down application of the methodology, starting with a macro-level analysis to identify circular economy categories with low performance in the country. A sensitivity analysis is conducted to determine the indicators most significantly impacting circular economy improvement. These findings inform the development of priorities and government-led actions to enhance circular economy practices. Subsequently, an operational plan is created for improving circular economy performance at the micro-level of typical companies, including an economic evaluation of the circular transition.

The study shows that Slovenia's overall circularity index stands at 51.8 points. While water and waste management exhibit strong performance (sub-indices between 70 and 80), materials, energy, and emissions lag behind with sub-indices below 50. Sensitivity analysis highlights energy and emissions as key drivers. A 10 % increase in renewable energy or a 10 % decrease in greenhouse gas emissions boosts the overall index by 1 % and 2 %, respectively. Implementing the National Energy and Climate Plan (Republika Slovenija, 2024) to decarbonize electricity by 2033 could elevate the index to 56.1 and reduce emissions by 40 % compared to 2005 levels. Achieving a 26 % share of renewable energy in transport would further increase the index to 58.1 and cut emissions by 49 %.

The focus then shifts to the micro level, targeting energy-intensive companies to increase renewable energy adoption. Given fossil fuels constitute approximately 30 % of the country's electricity mix, the analyzed company is encouraged to generate one-third of its electricity from renewables. A solar power plant with an estimated capacity of 13 MWp and 8.5 MWh battery storage is proposed. This investment, estimated at 11.5 million EUR (IRENA, 2023), is projected to yield a payback period of 5 to 7 years through electricity cost savings. Consequently, the company's energy sub-index would rise by 4.6 points (47 %). This correlation suggests that achieving a one-point increase in the overall circular economy index through renewable electricity generation would require investments in the order of magnitude of 10 to 15 million EUR, highlighting the potential benefits of government subsidies.

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Keywords: Circular economy monitoring, Circularity index, Sensitivity analysis, Macro and micro levels, Renewable energy impact

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Green Construction Materials

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Reducing CO_2 emissions is pivotal for advancing sustainability within the construction industry, given that Portland cement production alone accounts for 8-10% of global CO_2 emissions. Currently, numerous advanced technologies have emerged to lower CO_2 emissions from cement and concrete production. Among these innovations, a particularly promising approach involves partially substituting cement with residues, aligning with the principles of the circular economy (CE Center, 2019).

In this study, fly ash from Thermal power plant REK Bitola, glass residues (ACRON glass recycling), and dolomite as tailing residue were used to partially replace cement (CEM I 52.5 R and CEM II/B-V 42.5R) in the formulation of mortar and concrete.

In addition, crystalline admixture (Hidrobof Kristal – produced by ADING AD Skopje), graphite oxide-GO and nano Al_2O_3 were also used. The study investigated the impact of substituting cement with these residues on the fresh mortar properties, hardened mechanical properties, and self-healing characteristics. Fly ash was mechanically activated prior to its utilization (less than 20 % residue on the 32 μm sieve), dolomite was also ground and milled (< 125 μm), and glass was used as received from the supplier (<150 μm). Two series of mortars were designed. The first one incorporated 16wt.% mechanically activated fly ash a substitute for CEM I 52.5 R cement, followed by the addition of (i.) 1 wt.% crystalline admixture, (ii.) 0.001 wt.%GO, and (iii.) 0.25 wt.% nano Al_2O_3 to the mortars was followed. The second series involved substituting CEM II/B-V 42.5R cement with (i.) 10 wt.% glass, (ii.) 10 wt.% dolomite and (iii.) 5 wt.% dolomite and 5 wt.% glass. Referent mortars were used for comparison in both cases. The water-to-cement ratio was maintained at 0.5 for all tested mortars.

The substitution of cement CEM I 52.5 R with mechanically activated fly ash and the addition of crystalline admixture, GO and nano Al_2O_3 caused a delay in the setting time, but no particular changes in the consistency of fresh mortars. Regarding mechanical properties, the substitution of 16 wt.% cement with mechanically activated fly ash resulted in an enhancement of the compressive strength (4.4%) compared to the reference mortar (Stefanovska, 2024), and the addition of GO and nano Al_2O_3 met the expected values for the mechanical properties of conventional mortars. The best self-healing efficiency was achieved with the mortar containing 16 wt. % mechanically activated fly ash and crystalline admixture (39 % after 28 days and 96 % after 65 days of curing).

The substitution of CEM II/B-V 42.5R cement with glass and dolomite residues caused a delay in the setting time and met the expected values for the mechanical properties of conventional mortars. The self-healing efficiency of reference mortar was 65 % after 28 days of curing, but mortars with glass and dolomite addition do not show the expected effect. The investigation of the influence of glass and dolomite residues in concrete samples is in progress.

The study presents the preliminary results for supporting the circular economy, resource efficiency and decarbonization in society in the frame of smart specialization, green and digital transition aims.

Keywords: mortars, concrete, residue, mechanical properties, self-healing

Acknowledgment

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Investigation of Ciprofloxacin Adsorption on Carboxymethyl Dextran Surface-Modified Magnetic Iron Oxide Nanoparticles

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The increasing prevalence of antibiotics in water bodies represents a significant environmental challenge, underscoring the need for the development of effective removal strategies. This study presents a novel approach to synthesizing surface-modified nanoadsorbents with polysaccharide carboxymethyl dextran, for removal of problematic antibiotic ciprofloxacin (CIP) from aqueous environment. The research outlines the successful synthesis and modification of magnetic iron oxide

nanoparticles (MNPs) to enhance their binding affinity for CIP, potentially offering a groundbreaking solution for water treatment facilities.

The synthesis of MNPs with coprecipitation was meticulously confirmed through a range of analytical techniques, including attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR), X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD), and transmission electron microscopy (TEM). These methods collectively validated the presence of Fe-O bonds, the cubic spinel crystal structure characteristic of MNPs, and the superparamagnetic properties of the nanoparticles in size of about 13 nm.

Bare MNPs were further surface modified and modification played a pivotal role in augmenting the adsorption capabilities of the MNPs. The application of a carboxymethyl dextran (CMD) polymer coating was verified through ATR-FTIR and XPS, thermogravimetric analysis (TGA), and magnetic measurements, which demonstrated a CMD-induced decrease in magnetisation. The coated MNPs@CMD exhibited predominantly negative surface charges, as evidenced by zeta potential measurements, which indicated the presence of CMD coating. The latter was attributed to the deprotonation of carboxyl groups.

Keywords: Nanoadsorbents, carboxymethyl dextran, Ciprofloxacin Adsorption, iorn oxide Nanoparticles (MNPs), Surface Modification, Water Treatment Technologies

Acknowledgment

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Complete Continuous Time/Temperature-Dependent Mass-flow and Locally-normalized Abiotic Depletion Potential of Phosphorous in a Spatially-optimized Cherry Orchard

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Critical raw materials (CRMs), defined as raw materials without viable substitutes, are assessed every 3 years by the European Commission according to their economic importance and supply risk. The first list was published in 2011 and contained 14 CRMs, while in 2023 the list was enlarged to 34 CRMs. To this list belongs also phosphorous (P), which is essential for the healthy development and growth of plants, humans and other animals: while plants receive P from the soil, humans and other animals through plants/animals.

However, the largest reservoir of P is sedimentary rocks, which are not renewable and are scarce in Europe (one P-rock mine is in Finland and one in Marocco). Therefore, efforts to reach the local sustainability of P in food consumption through a circular economy approach are crucial.

Of all CRMs, P is the only one for which agricultural consumption can be considered as a continuous temperature-dependent function, while for all the rest consumption has no natural continuous dependence and is driven solely by the current industrial and technological needs. Although temperature varies daily and is increasing due to climate change, it can be predicted well enough so that temperature dependence can be replaced by time dependence, where time lasts one revolution of Earth around the Sun, after which everything repeats.

The mass flow of P, where its consumption by plants was approximated by two Gaussian peaks (big in spring, small in autumn), was calculated for a cherry orchard by excluding competition for nutrients among cherry trees, i.e., cherry trees were planted spatially as close as possible, so consumption of nutrients in the orchard has only one spatial dependence (depth). Therefore the boundary condition of the system was considered as the surface area covered by one cherry tree multiplied by the depth from which P can be uptaken. Inside the system, there was P available for plants and P in a form not useful for plant uptake. An additional condition was that input of P from the outside was not allowed to mimic conditions when P-mines will be depleted or P will not be available on the market.

Additional parameters that were taken into account in the mass flow:

a) uniform distribution of all nutrients as an initial state,
b) three types of soil (different initial amounts of P),
c) no cover, low and high P-consuming cover,
d) mulching and mowing the cover,
e) leaving/removing bad products from the orchard,
f) removing good products from the orchard,
g) rain and wind,
h) being able to change P from non-useful to plant-useful.

Local abiotic depletion potential was calculated after every Earth's revolution and normalized to the whole remaining system (instead of antimony).

The aim was to determine the best approach to prolong the final depletion of P from soil, which is: having low P-consuming cover, mulching of cover, and leaving bad products to rot in the orchard.

Keywords: Abiotic depletion potential, Mass flow, Recycling, Substitution, Critical Raw Materials, Phosphorous, Life Cycle Assessment, Circular economy

Acknowledgment

This work is part of the ARIS project of Dr Alenka Mauko Pranjić and was financially supported by the Slovenian Research Agency under Grant No. J1-3029 and also by Slovenian Research Agency program group no. P2-0273.

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BOOK OF ABSTRACTS
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Development of Complete Regional and Global Abiotic Potential Normalized to Constant Mass Values of the Extraction-Region and Extraction-Planet

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Phosphorous (P) plays an essential role in agriculture, industrial applications, environmental management and human/animal development, body functioning and health.

Because Europe has limited domestic P-sources, the import of P plays a significant role, which makes Europe vulnerable to price volatility and supply disruptions, especially when importing from geopolitically less stable regions. Therefore, P is for Europe one of the critical raw materials (CRMs) and research in its recycling potential from different waste streams (animal manure, sewage sludge etc.) is being performed on national and international levels.

To address the challenge of scarcity of P in Europe, we reformulated the abiotic depletion potential (ADP) into abiotic potential (AP; how much abiotic species is left in Earth's crustance per region; in mass percentage) and abiotic depletion (AD; how much of abiotic species was excavated per region; in mass percentage), both normalized to constant masses (taking into account the law of conservation of mass, and that no material gets to Earth from outer space and no material from Earth is lost to space: boundary condition is therefore Earth). Normalizations were therefore performed on:

- The initial mass of the species (P) in the selected region, or on Earth;
- The initial mass of the selected region, or Earth's mass.

Global AP and AD are the sum of all regional AP and AD, respectively, all normalized to global values (of selected CRM species on Earth or Earth). Their sum (of AP and AD), per region or globally, is always 100%.

However, to approach the depletion of CRMs (P in our case) holistically, all mass flows have to be taken into account (and normalized on global values): between regions (positive mass flow is into the region, negative is out from region), as also (time-dependent) retention of the CRMs in the products, (permanent) loss of the material, recycling and potential substitution. Substitution positively affects AP, however, this is a negative effect for AP of the substitute. Nonetheless, the substitute (if it exists) usually offers weaker performance. Therefore, the calculated positive effect of substitution is not just a decrease of the mass that would be excavated in (molar) 1 to 1 ratio, but is multiplied by the performance ratio between the substitute and the substituted CRM (P in our case). If the recycled CRM does not give as good performance as the CRM from the raw materials, the performance ratio is applied also for recycling, and the difference in masses becomes (not permanently) lost CRM.

To predict the future outcome, the yearly need of P was connected by the population number for each continent, taking into account that all the needs are met (and not exceeded). The yearly population growth ratio was compared to the abiotic potential coefficient (APC) and abiotic depletion coefficient (ADC), which are a derivative of AP and AD between subsequent years.

Nonetheless, the positive conclusion is that mass is conserved, and the negative is that material is being lost in all the regions.

Keywords: Abiotic potential, Abiotic depletion, Recycling, Substitution, Critical Raw Materials, Phosphorous

Acknowledgment

This work is part of the ARIS project of Dr Alenka Mauko Pranjić and was financially supported by the Slovenian Research Agency under Grant No. J1-3029 and also by Slovenian Research Agency program group no. P2-0273.

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Study of Activation and Stability of Freeze-Dried Milk Kefir

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Kefir is becoming increasingly popular due to new research because of its health benefits. It is usually made by adding either a starter culture called kefir grains directly or a percolate of the grains to milk. The grains can be recovered at the end of fermentation (John et al., 2015). Freeze-drying is a method of choice for long-term preservation of bioactive materials. This dehydration method causes low shrinkage and results in a fully soluble product that can be easily rehydrated. In addition, freeze-drying is often used for the preservation of lactic acid bacteria starter cultures in the fermentation of dairy products and foods (Hsi-Chia et al., 2006). The dehydration of kefir and the production of freeze-dried instant powder was the challenge of our research.

The experimental work began with the freeze-drying of the previously prepared milk kefir. The freeze-dried kefir in the form of a light powder was further used as a starter culture by adding it to the milk in varying amounts (0.5 g - 12 g freeze-dried kefir per 200 mL milk). The activation time was about 24 hours. The kefir was successfully produced in all cases. We kept the temperature at 23 °C. Four process parameters were monitored for 3 days: pH, concentrations of CO_2, sugar and

ethanol. An ion-selective electrode, high-performance liquid chromatography and a pH meter were used for this purpose. We found that pH decreases as the amount of freeze-dried kefir increases. The CO_2 concentration increases with increasing amount of freeze-dried kefir. When measuring the sugar concentration, we observed a decreasing concentration trend. The ethanol concentration was too low to be detected until the last, third day of measurement, when it appeared in very low concentrations at the highest amount of added freeze-dried kefir. On the chromatogram, we observed the presence of additional peaks. We suspected that this could be lactic acid or acetic acid, but could not confirm this as the results were inconclusive.

We then tested the formation of kefir by adding a certain amount (1.0, 2.0 and 4.0 g) of kefir, obtained using freeze-dried kefir as a starter culture, to 200 mL of milk. In all cases, fresh kefir was produced, even after adding less than 1.0 g of the starter culture. We repeated the process five times and confirmed the formation of milk kefir. The quality of the kefir was checked using the four process parameters mentioned above and compared with those of the original kefir.

To summarize, we confirmed that kefir can be successfully produced from freeze-dried milk kefir powder. The quantities of starter cultures required are very small, which is a major advantage of the method. At the same time, it can be a solution to increase the market value of this milk drink.

Keywords: milk kefir, freeze drying, pH, CO_2, sugar

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Development and Stabilization of a New Beverage From Lyophilized Water Kefir

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Water kefir is a fermented beverage obtained by fermenting sugary water with water kefir grains. After 2 to 4 days of anaerobic incubation at room temperature, a bubbly, yellowish fermented beverage with fruity, tart notes with a hint of sweetness and a subtle alcoholic aroma is produced (Laureys et al., 2014). Kefir grains consist of a consortium of yeasts and lactic acid bacteria embedded in a natural matrix of the exopolysaccharide kefiran (Azizi et al., 2021).

The main objective of our research was to determine whether a new fermented beverage with a taste like water kefir can be produced from lyophilized water kefir. We investigated the stability of the resulting beverage and the effect of artificially added CO_2 on the stability of the beverage. We also wanted to determine the optimal mass ratio of lyophilized water kefir to sweetened water that would produce a beverage most comparable to the original water kefir. The quality of this new beverage was tested by tracking the concentrations of sugar, CO_2 and ethanol as well as pH during the fermentations. We used high-performance liquid chromatography,

ion-selective electrode and pH meter to monitor the selected bioprocess parameters. We first measured these parameters immediately after preparing the beverage from lyophilized water kefir and water. Then we repeated the measurements weekly until the fourth week, when the beverage was no longer stable. In general, we confirmed that the sucrose concentration decreases every week, while the concentration of fructose and glucose increases in both samples (with and without added CO_2). The pH value of the beverage decreases and is lower at higher mass ratios. The samples with added CO_2 have higher sugar concentrations and a lower pH value than the samples without added CO_2. In the samples without added CO_2, we also measured the CO_2 content, which was lower than in the samples with added CO_2, but increased from week to week. The ethanol concentration increased over time and was higher in the samples with added CO_2.

Temperature had a significant effect on the stability of the new beverage. The drink was not stable at room temperature. The measurements could no longer be carried out after the first week, as the bottles containing the samples became bloated. We can conclude that the drink most similar to water kefir can be prepared with a ratio of 14 g of lyophilized water kefir to 100 mL of water. It can be stored in the refrigerator for two weeks before it loses its stability.

Keywords: water kefir, lyophilization, fermentation, CO_2, sugar

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Characterization of Hydrolyzed Waste Eggshell in the Subcritical Water as Coating Suspension to Be Used for Functionalization of Textiles

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Eggshells are rich in calcium carbonate and other minerals, making them a potential source of valuable ingredients. Eggshells can be hydrolyzed under subcritical water conditions to yield calcium ions and carbonate ions from calcium carbonate, amino acids and peptides from proteins, and other minerals such as magnesium, phosphorus, and potassium (Cheng et al. 2021).

In this research, the chicken and quail eggshell powders were hydrolyzed using subcritical water at temperatures of 150 °C or 240 °C and a pressure of 100 bar for 2 hours. The hydrolysate, which will be later tested as a possible finishing agent for

cotton and PES, was characterized. The pH of the water solution after subcritical water hydrolysis of eggshells is pushed toward higher values due to the release of calcium ions (Ca^{2+}) from the eggshells. The composition analysis revealed only a small variation in carbon and nitrogen content between chicken and quail hydrolyzed eggshells and no presence of sulfur, indicating that at these conditions the C-S bonds are not broken. The zeta potential is in the range of -16 to -28 mV, identifying the particles with a negative charge and a suspension of good stability. The hydrolysate gives colloid and microparticles with a large range of particle sizes (20–3000 nm). The turbidity is quite high and varies (12-209 NTU) with type of eggshells (higher turbidity for quail eggshells) and used temperature. The electrical conductivity of quail eggshell hydrolysate is up to 5000 μS/cm higher than in the case of chicken eggshells, and it rises with temperature, probably due to different concentrations of Ca^{2+} and CO_3^{2-} ions. Quail eggshell hydrolysates also have lower surface tension than chicken eggshells, and higher applied temperatures result in lower surface tension.

The antioxidant activity was analyzed by the spectrophotometric method using ABTS. The hydrolysates exhibit high antioxidant activity (95.7-98.6 %) after 15 minutes.

The subcritical water hydrolysis of waste eggshells shows promising application as a textile finishing agent with antioxidant activity.

Keywords: chicken and quail eggshells, subcritical water hydrolysis, optimization, textile finishing, zeta potential, particle size

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GEORIS PAVERS – Small Scale Demonstration Within Georis Project

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Alkali activation is a growing global technology in which a solid aluminosilicate precursor reacts with an alkaline activator at room temperature to produce a hardened product (Provis et al., 2018). Recently, metallurgical slags (i.e. non-ferous slags, ladle slag) have been used as a sole precursor for alkali activation (Pontikes et al., 2020, Adesanya et al., 2017). The aim of the KIC Georis project (Novel geopolymerization technology for environmentally sustainable construction materials), co-funded by the EIT RawMaterials, was to demonstrate the practical applicability and efficiency of alkaline activation technology, using metallurgical by-products and residues as primary raw materials . GEORIS pavers were developed as part of the project. The mix-design, developed by KU Leuven, uses 78 % of

metallurgical residues, of which 62 % comes from SIJ Acroni's recycled steel slag. The Ekominit S1, processed mixed EAF stainless steel slag and ladle slag from SIJ Acroni, secondary copper slag and ground granulated blast furnace slag (GGBFS) were used as binder. Majority of sand was replaced by EAF C slag aggregate, and thus saving natural sources.

More than 20 m² of pavers were produced in a mobile unit designed for pilot production. After curing, these pavers were laid on the SIJ Acroni site. GEORIS pavers showed good frost resistance, abrasion resistance and flexural strength, indicating that the properties of GEORIS pavers are comparable or even superior to those of commercially available concrete pavers.

Compared with conventional pavers, paving an area of 1 m² with sustainable geopolymer pavers would save 27 kg CO_2. GEORIS pavers show a significantly lower impact on freshwater eutrophication compared to commercially available concrete pavers.

The results thus contribute to the ambitious goals of the steel processing industries to achieve zero waste and demonstrate the principle of industrial symbiosis.

Keywords: alkali activation, steel slag, pavers, demonstration, performance

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Design and Production of Sustainable Wrought Aluminium Alloys Using Artificial Intelligence

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Aluminium alloys are solid solutions and subject to the Hume-Rothery rules. These rules set the maximum-allowable concentrations of the alloying elements. However, defining the limits in this way makes recycling considerably more difficult. The chemical composition of scrap material is less well defined than the composition of primary aluminium. This is especially true of the scrap from end-of-life products.

The goal is to create wrought aluminium alloys with wider concentration intervals of alloying elements or with a large proportion of scrap material. Despite their modified (or at least non-standard) chemical composition and the modified process path of their preparation and processing, they would still satisfy an appropriately modified set of customer requirements. The realisation of this objective would contribute to the circular management of aluminium and increase its added value. The problem is that the different aluminum alloys contain more than 30 alloying elements. There are also many parameters by which we define the process path and the properties prescribed by the customer. As such, the processing with so many variables requires the use of artificial intelligence.

The artificial intelligence (AI) we used to design process paths (IBM IWM) scanned all the accessible process paths and created a subset of equivalent process path, i.e., all those with which we can achieve the desired set of properties. From this it was possible to select from among them only those that have the widest intervals in pre-selected components. We tested the selected process path as defined by AI in practice and compared the obtained properties with those that were predicted. Together with each individual composition, the AI identified and defined the remaining production parameters of the process path.

The research introduces alternative wrought aluminium alloys that can be produced by direct scrap remelting based on end-of-life products. A key innovation is the process routes for obtaining these alloys, designed with the help of artificial intelligence.

Keywords: recycling, artificial intelligence, wrought luminium alloys, post-consumed scrap, alternative composiitions

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BOOK OF ABSTRACTS
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Development of a Carbon-Neutral Primary Magnesium Production Technology Based on the Low-Cost Aluminothermic Reduction of MgO

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Primary magnesium is the raw material used to produce many automotive and aerospace alloys. The Impol Group, like other companies in the EU, imports it mainly from China, despite there being rich deposits of dolomite in Slovenia and inexhaustible reserves of $MgCl_2$ in the sea, from which primary magnesium could be produced. However, existing procedures are technologically demanding, costly and have a negative impact on the environment. The aim of this research was to develop a cheaper technological process that enables the environmentally friendly production of "green" primary magnesium.

The aluminothermic reduction of MgO has been studied in detail, but in the cases described the aluminum powder is used as a reducing agent and not as a melt, which is a key feature of our solution. As an input material we used low-cost scrap aluminum from end-of-life products. The production process is schematically

presented in Fig. 1. The resulting magnesium is in a gaseous state. With argon, it passes into a condenser, where it transforms to the liquid state. The by-product of the MgO reduction is spinel, which makes the process more economic. Another innovation is the method of introducing the MgO particles into Al melt, in the form of a filled wire, with an aluminum outer and MgO particles in the core. The progress of the chemical reaction was monitored "on-line", with the help of measurements of the electrical conductivity of the suspension based on Al melt and MgO particles admixed with it. For comparison, a laboratory determination of the concentration of aluminum in the suspension was conducted. By optimizing the parameters of the process, we have shown that it can take place continuously and at atmospheric pressure, and in a flowing atmosphere of argon, which makes the production even cheaper.

The mechanism of aluminothermic reduction of MgO can be described using the non-reacted-core model. The MgO particles react with the Al melt, forming the "activation complex" $MgO\cdots Al_2O_3$ and magnesium in the gaseous state (equation 1). Subsequently, spinel ($MgAl_2O_4$) is formed from the activation complex, which is described in equation 2.

$$4MgO_{(s)} + 2\,Al_{(l)} \rightarrow MgO_{(s)}\cdots Al_2O_{3(s)} + 3\,Mg_{(g)} \quad (1)$$

$$Al_2O_{3(s)}\cdots MgO_{(s)} \rightarrow MgAl_2O_{4(s)} \quad (2)$$

Based on the experimental results and the developed model, we determined a process window that ensures the highest yield of chemical reactions (1) and (2) and the optimal ratio between the input or production costs and new value created. The mixture of products formed under the conditions described above contains approx. 70 % magnesium, approx. 20 % $MgAl_2O_4$, approx. 5 % Al_2O_3 and approx. 5 % unreacted MgO. Computationally and experimentally, we confirmed that this is an optimum for the defined boundary conditions. The carbon footprint of the produced magnesium is between 2.5 and 3.3 t CO_2/t Mg.

Conclusions

We have improved the process of obtaining primary magnesium, based on the aluminothermic reduction of magnesium oxide. The innovations we have introduced make it possible to obtain low-cost and low-carbon primary magnesium.

Key improvements include: (i) the extraction of magnesium oxide from seawater with solar energy, (ii) the use of aluminum melt obtained from scrap based on end-of-life products and (iii) a new way of introducing and dispersing MgO particles into the Al melt. Finally, we verified the effectiveness of the improvements on the laboratory scale and produced a feasibility study for a production plant with a capacity of 10,000 t Mg/year.

Keywords: magnesium, aluminothermic reduction, reducent, post-consumed scrap, spinel

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Social Life Cycle Assessment of Plastic Materials and its Alternatives for Packaging

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Being one of the three pillars of sustainability, social impacts are increasingly recognised, yet remain inadequately assessed compared to environmental and economic aspects. This gap is pronounced in the evaluation of packaging materials, such as plastic and its alternatives, where social impacts are rarely evaluated. This study employs Social Life Cycle Assessment (S-LCA) to evaluate both positive and negative social impacts associated with the entire life cycle of plastic and its alternatives like paper and cotton. The assessment, based on stakeholder groups including worker, local community, society, value chain actors, consumers, and children, will be conducted using OpenLCA by integrating foreground data obtained

from industrial sources and literature reviews, all linked to a SOCA database. The derived results will be presented in a scoring system categorising different risk levels. Social hotspots for sustainability improvement in the packaging industry, such as working hours, safe and healthy living conditions, technology development, fair competition, consumer privacy, and education provided in the local community, will be detected, providing recommendations for decision-making to mitigate negative social impacts.

Keywords: Social Life Assessment, Packaging, Plastic, OpenLCA, SOCA

Acknowledgement

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Characterization of Incineration Ashes for Sustainable Recycling in the Construction Industry

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Ashes produced from incineration processes are complex materials characterized by significant variability in their composition. Each type of ash possesses unique properties due to differences in thermal processes and operational practices at incineration plants, leading to variations not only between different facilities but even within the same plant. Factors such as the type and source of incinerated materials, local environmental conditions, batch processing, and the specific collection mechanisms used also influence the resulting ash composition. Additionally, the physical handling and logistics of ash management can further alter its properties. For instance, ashes from various processes are often mixed before transport, and water is typically applied to stockpiles at ash yards to prevent dust formation. The time ash is exposed to atmospheric conditions is another critical consideration. Consequently, each ash type requires individual analysis, as these

variables contribute to inconsistencies in performance and hinder effective recycling (Zhao et al., 2018).

The construction industry is an ideal sector for recycling industrial by-products like ash, as it offers two key benefits: the efficient use of large quantities of materials and the permanent immobilization of harmful elements during earthworks, achieved by leveraging the beneficial properties of certain ashes. The introduction of anthropogenic construction products into earthworks was standardized in April 2019 through SIST EN 16907-2 (2019), allowing the use of processed natural materials, manufactured materials, including secondary and recycled materials, in construction composites.

This study aims to emphasize the importance of thoroughly characterizing incineration by-products, such as coal ash, biomass ash, and ash from the co-combustion of various fuels, prior to their recycling in different applications. The research emphasizes the necessity of accurately defining key properties, including physical properties, microstructure, phase and chemical composition, to evaluate the recycling potential of ash. These insights facilitate informed decision-making for sustainable resource management. Our research presents a detailed characterization of various ashes from Slovenia, offering a comparative analysis with some ashes from neighbouring countries.

Keywords: waste by products from incineration ashes, recycling, physical properties, phase composition, (latent) hydraulic properties, hydration

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Environmental Impact Evaluation of Biomass-Based Steam Rankine Cycle

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Combined production of heat and electricity is suitable for both, fossil and biofuel (biomass) combustion systems, and presents a viable solution for energy saving and environmental preservation. Biomass cogeneration is considered an effective alternative for reducing greenhouse gas emissions due to its low CO_2 emissions, and with the recent technological advancements it is suitable for large, medium and small cogeneration systems. This study evaluates environmental impacts of biomass utilization through combustion in the steam Rankine cycle, which is a conventional heat engine using water/steam as the working fluid. The mathematical model is first developed and optimized in GAMS by maximizing the power output of the system. Life cycle assessment is further conducted to evaluate the environmental impact of the system based on a functional unit of 1 MWh of energy generation, by using a cradle-to-gate approach and Ecoinvent database. The system is assessed across 11 impact categories using reference energy generation mix. Based on a case study of a relatively small municipality in Slovenia, the system under optimal operating conditions can generate almost 536 kW of electricity and over 2000 kW of heat. The findings indicate promising potential for environmental impact mitigation, with

negative values across all impact categories, indicating overall environmental unburden.

Keywords: Life cycle assessment, steam Rankine cycle, cogeneration, environmental impact, process optimization

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Evaluation of Different Fire Scenarios in School Classroom, Considering the Impact on Global Warming Potential

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Analysis of fire incidents and effectiveness of fire safety measures was conducted for a secondary school based on the Home Office fire statistical data to determine the most environmentally friendly fire safety design. Inventory data of all combustible materials in a prototype building were gathered for furniture, whiteboard, windows and doors as well as for some other materials and products that potenttialy need replacement in the case of fire incident such as vinyl and floor heating systems. The most frequent fire scenarios were identified based on fire locations, automatic extinguishment systems and compartmentation as fire spread

and building damage could be highly influenced by the presence and effectiveness of fire safety measures. Fire damage caused by fire and total damage, which also include damage due to smoke and water used during extinguishment operations, were estimated using statistical data and engineering judgment for the selected fire scenarios. Environmental burdens of the fire refer to end-of-life treatment with damaged materials (disposal, recycling) and replacement with new materials. However, the environmental impact related to fire plume emissions and the use of fire extinguishment agents were omitted from the study. Life Cycle Assessment (LCA) method was applied to evaluate the Global Warming Potential (GWP) of different fire scenarios and fire safety measures. Impacts on other indicators , which are predominantly affected with fire plume emissions, were not considered as these kind of emissions were neglected in the study due to their challenging nature.The environmental burden (e.g. GWP total) expressed in kg CO_2 equivalents) of a fire scenario with fire suppression system (installation of sprinklers) was benchmarked against the environmental burdens of a scenario without fire suppression systems. These outcomes aim at supporting decision-making in the fire safety strategy of future sustainable and fire-safe buildings.

Keywords: fire scenarios, school, fire suppression system, LCA, Global Warming Potential

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Enhancing Orange Waste Value: In Situ Extraction of Active Compounds Through in Silico Predictions

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Annually, the food-processing industry generates millions of tons of orange peel waste, rich in valuable active compounds like limonene. Limonene, a key component of orange essential oil, is prized for its aroma and antimicrobial properties in various industries. Nowadays, traditional extraction methods using toxic solvents like hexane are being replaced by sustainable deep eutectic solvents (DES) (Ma et al.). DES comprise hydrogen bond donors (HBD) and acceptors (HBA), which can be tailored for specific applications and since it is a greener solvent it can also enhance the value of the final product. Our goal was to create a DES to extract limonene from orange peels that could be directly applied in cosmetic formulations, eliminating the need for additional separation steps.

Initially, we conducted *in silico* investigations using COnductor like Screening Model for Real Solvents (COSMO-RS) to assess limonene solubility in various organic solvents and DES (Wojeicchowski et al.). The findings revealed that limonene predominantly engages in hydrophobic interactions rather than polar interactions. Notably, a specific HBD identified in the COSMO-RS calculations showed potential for high limonene extraction efficiency, despite not being a typical hydrophobic solvent. Building on these results, we selected promising combinations of HBDs and HBAs for further *in situ* experimentation. This involved exploring the formation of theoretically predicted DES, and optimizing molar ratios and water content to achieve the desired viscosity. Prior to solid-liquid extraction on orange peels, we fine-tuned parameters to maximize limonene extraction yield. Subsequently, extractions were carried out using 15 selected DES and 5 organic solvents for comparison with traditional methods. Limonene analysis was conducted using gas chromatography-mass spectrometry, with an additional liquid-liquid extraction step necessary to allow limonene quantification since DES are non-volatile. Furthermore, the extracts underwent characterization via high-performance liquid chromatography for flavonoids and toxic furanocoumarin bergapten detection and quantification.

Through the utilization of *in silico* COSMO-RS analysis, we saved time and resources while identifying the most promising solvents to extract limonene. This was further proved through the effective *in situ* extraction of limonene from orange peels, yielding higher extraction efficiency in comparison to traditional methods involving organic solvents. The resulting orange peel extract also contains flavonoids, offering added advantages to cosmetic formulations. This study demonstrates the successful valorisation of orange peel by-products through a greener and sustainable approach, potentially replacing environmentally taxing extraction processes reliant on organic solvents.

Keywords: waste valorization, orange peel, limonene, COSMO-RS, DES

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Investigating the Impact Of LECA-To-Natural Aggregate Ratios On Lightweight Concrete Composites

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Extensive research is being carried out on energy-saving and efficient materials due to the scarcity of energy resources. LECA is a versatile material utilized in construction. Lightweight Expanded Clay Aggregate (LECA) is produced through the thermal expansion of natural clay at high temperatures. LECA is characterized by its lightweight, porous structure, and spherical shape. The lightweight nature of expanded clay aggregate can be attributed to the presence of multiple distinct honeycomb-like air spaces that are formed within and between its aggregates (Rashad, 2018), providing reduction of construction dead load, and a low thermal conductivity coefficient (as low as 0.097 W/mK (Hammer et al. (2000).)). In the field of construction, using concrete in combination with LECA as an additive to improves its thermal properties and results in a composite that has reduced dead load. In essence, it becomes a lightweight concrete composite with insulating properties.

This paper takes a closer look at the resulting properties of changing the ratio of LECA to natural aggregate in a lightweight concrete composite.

After settling on a standard concrete mix for the reference, we replaced the mineral aggregate in different fractions and ratios, resulting in 8 different composites containing LECA. The samples, prepared in accordance with SIST EN 12390-1 and SIST EN 12390-2 standards, were tested after twenty-eight days for compressive and flexural strengths, and thermal conductivity. Additionally, the concrete composites were tested for density in their wet-mixed state.

According to (Dabbaghi F. et al., 2022), expanded clay aggregate predominantly comprises SiO_2, Al_2O_3, Fe_2O_3, CaO, and also contains alkalis like Na_2O and K_2O. As the mechanical properties are influenced by the interface connection between LECA and cement composite matrix, we looked at the mineral components of LECA aggregate using a SEM EDX analysis. Noticing the ratio of silicon to calcium being low at the interface indicated a strong connection, which explains the moderate retention of strength shown during sample testing.

For the flexural strength, the samples were tested applying a centric bending load test using the Zwick Roel Z10 device. Compressive strength was tested using a hydraulic press. Thermal conductivity was evaluated using a HotDisk™ device which utilizes a process of heating and cooling the sample in a controlled environment.

The samples showed slightly diminished compressive and flexural strengths. Looking at the thermal conductivity of the samples, it can be noticed that the samples containing a higher percentage of LECA aggregate have a lower thermal conductivity.

In conclusion, claims can be made that the LECA-enhanced concrete composite exhibits a superior strength-to-weight ratio compared to traditional concrete composite. The LECA-enhanced concrete composite has the added benefit of low thermal conductivity, making it double as an insulating material.

Keywords: Lightweight expanded clay aggregate, Lightweight concrete, Thermal conductivity, composites, mechantical properties, workability, components analisys.

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Unlocking Value From By-Products in Slovenia's Bioeconomy

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Slovenia have a significant raw material potential for development of the bioeconomy, but it has similar as other Central and Eastern European countries sub optimally exploited potential. There is a great need to increase the growth potential of the bioeconomy, which will bring Slovenia not only new jobs, but also environmentally friendly technologies and better prospects for the future (Juvančič et al., 2021).

The Interreg CE project TeBiCE focuses on Territorial Biorefineries for Circular Economy and presents its contribution results. The project explores the utilization of biomass, by-products, and residues from primary production and the agri-food processing industry as a new source for producing high-value components. TeBiCE identifies three key sectors for evaluation: fruit production and processing (grape and apple), oil production and processing (olive and pumpkin seed), and wood processing industry, particularly timber (wood bark). Within this framework, six value chains (VC) were developed and assessed: grape pomace VC, red grape pomace VC, apple pomace VC, olive pomace VC, pumpkin seed cake VC, and wood bark VC.

By products such as grape pomace, apple pomace and olive pomace are reach source of various phenolic components and also of polysaccharides like pectin (Sirohi et al., 2020; Costa et al., 2022, Millan-Linares et al., 2021). In ore VC of grape pomace, apple pomace and olive pomace, possibilities for pectin production from grape, apple, olive pomace was evaluated. Pumpkins seed cake is residue of pumpkin oil production and contain high amount of fibres and proteins and is usually used for animal feed. Because they high nutritional value is interested also as functional food ingredient (Singh, 2024). The potential of protein flour production from pumpkin seed cake was evaluated in VC of pumpkin seed cake. The main by-product from timber industry is wood bark that contain wide range of natural component. Tannins are one of high interest because wide range of applications (Das et al., 2020). Production of tannins from wood bark was evaluated in VC of wood bark. The potential of selected VCs in Slovenia was evaluated by Value Chain Generator® artificial intelligence tool (vcg.ai).

Keywords: bioeconomy, project TeBiCE, value chain, evaluation, grape pomace, apple pomace, olive pomace, pumpkin seed cake, wood bark, Value Cain Generator ®

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Influence of Gloss on Visual Appearance of Pearlescent Pigments Printed on Packaging

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This study investigates the influence of gloss on the visual appearance of pearlescent pigments printed on polypropylene (PP) packaging, focusing on different viewing angles and background colours. Pearlescent pigments, known for their special luster and interference properties, are increasingly used in the packaging industry to increase visual appeal and differentiate products on the shelf. Five different pearlescent pigments (gold, polar white, red, blue and purple) with the same particle size were used in the study. All pigments consist of thin platelets of the natural material mica, which are coated with a wafer-thin layer of metal oxide.

The pigments were first printed on PP packaging paper and overprinted on black background ink using a screen printing process. The print gloss was measured at three different angles (20°, 60°, 85°) using a multi-angle glossmeter, and scanning electron microscopy (SEM) of the pigments was also performed.

The results show that the background colour significantly affects the final appearance of pearlescent pigments, with gloss being increased when printed on a black background compared to a white background. There was also a clear difference in print gloss measured at different angles, with the highest print gloss for all effect pigments being achieved at an angle of 85°, while it was lowest at an angle of 20°.

Keywords: Pearlescent pigments, print gloss, optical effect, luster, packaging

Acknowledgement

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Alginate Beads as a Promising Delivery System for Food Applications

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Introduction

There is a significant trend toward the use of biocompatible, biodegradable, and non-toxic carrier systems. Among the most important carrier systems for various therapeutic agents are polymer-based particles, as they are biodegradable, biocompatible, non-immunogenic, and non-toxic. A well-studied example is encapsulation in biopolymeric particles or beads, such as alginate beads, which are particularly suitable for food applications (Fernando et al., 2020; Kučuk et al., 2023).

On the other hand, agro-industrial waste from the fruit industry is a growing environmental problem due to improper disposal and underutilization. Mango is an excellent and widely appreciated tropical fruit. However, the enormous use of this fruit also produces various by-products, such as peels and seeds. Mango by-

products, especially peels, are a significant source of bioactive compounds, the utilization of which promises to reduce the volume of waste and environmental impact (Kučuk et al., 2024).

The aim of the study was to produce edible alginate beads with encapsulated mango peel extract (MPE) to protect valuable bioactive compounds from rapid degradation.

Methods

The ionotropic gelation method was used to develop alginate beads encapsulating mango peel extract (MPE), which was obtained by an ultrasound-assisted extraction process using ethanol as the extraction solvent. The entrapment efficiency and the *in vitro* release study under gastrointestinal conditions were determined using the UV-VIS spectrophotometer. The antibacterial activity of MPE-loaded alginate beads was validated against the growth of the Gram-negative bacterium *Escherichia coli* and Gram-positive bacterium *Staphylococcus aureus* using the plate count method.

Results

MPE was successfully encapsulated in alginate beads, achieving an encapsulation efficiency of 63%. An *in vitro* release study demonstrated the stability of the alginate beads in simulated gastric fluid (SGF). Conversely, complete release was observed in simulated intestinal fluid (SIF), indicating successful absorption in the human body. In addition, MPE-loaded alginate beads significantly inhibited the growth of pathogenic intestinal bacteria*, E. coli* and *S. aureus*.

Conclusions

MPE-loaded alginate beads represent a promising oral delivery system with considerable potential for high-value-added applications in the food industry, especially for the development of health-promoting products such as dietary supplements, functional foods, or food additives. In addition, the production of MPE-loaded alginate beads is characterized by its sustainability and cost-efficiency, as MPE is derived from waste materials, which significantly contributes to the circular economy and helps to reduce the environmental impact.

Keywords: alginate beads, mango peel extract, encapsulation, *in vitro* release, antibacterial activity

Acknowledgement

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Quality Assessment of Mobile Applications in the Field of Environmental Pollution

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Environmental pollution is an increasing concern around the world, impacting air, water, and soil quality, and consequently, human health. There are many ways in which people can be made more aware of the facts and consequences of environmental pollution. One effective approach is the use of mobile applications, which are widely available and used in today's digital age. The aim of the research was to assess mobile phone and tablet applications in Google Play and iOS app stores on the topic of environmental pollution according to application quality.

We reviewed mobile applications in the Google Play and iOS app stores, using the keyword "environmental pollution". In the review, we followed the PRISMA recommendations. We included mobile applications which were related to pollution topic in general, in Slovene or English, and freely accessible. Games, paid applications, and applications which were not in English or Slovene language were not included. Applications were evaluated using the Mobile Application Rating Scale (user version) by three authors independently. A total of 587 applications were

counted across all devices and both mobile stores after removing duplicates. Most mobile applications related to air pollution (*n*=246), followed by water pollution (*n*=85), noise pollution (*n*=53) and light pollution (*n*=18). We have found a lot of applications that deal with climate change and environmental change in general (*n*=185), while for other types of pollution only a few applications existed. Based on the inclusion and exclusion criteria, we included 8 applications in the final review. We have calculated the average of all the authors' grades and determined the highest and lowest ranked mobile applications. The overall uMARS scores for the applications ranged from 3.06 (±0.23) to 4.35 (±0.08). Most applications scored highest on functionality section, while most scored lowest on engagement section. Of all the applications evaluated, only one had an overall score higher than 4 (Earth Hero: Climate Change). Mobile applications can raise awareness about environmental pollution. Most of them effectively provide users with valuable information related to various types of environmental pollution. Although the current state of mobile applications is good, new applications equipped with reliable and quality sources of information need to be further developed, especially for each type of environmental pollution separately. To achieve continuous improvement, these applications should be evaluated using appropriate tools and questionnaires, as evaluations with suggestions could help developers to make progress.

Keywords: environmental pollution, mobile applications, review, air pollution, water pollution

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The Carbon Footprint of Different Construction and Demolition Waste Management Methods

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Introduction

Construction and Demolition Wastes (CDWs) pose significant environmental challenges, accounting for nearly half of all solid waste sent to landfills worldwide (Tonini et al., 2023). These wastes are particularly problematic due to their volume and weight, contributing to various issues beyond disposal. Concerns refer to problems such as resource efficiency and climate change, the latter is indirectly related to carbon embodied in CDW.

Methods

End-of-life treatment with three CDW fractions is considered in this study: concrete, wood, and steel. The goal of the study is to evaluate the Global Warming Potential (GWP) of circular versus linear end-of-life treatment approaches for the three

selected CDW fractions. Life Cycle Assessment (LCA) methodology was applied to calculate the GWP.

Results

In the case of waste concrete, the circular scenario refers to the recycling of broken concrete into recycled aggregate, which can be used for road construction or the concrete industry. The linear scenario includes the landfilling of waste concrete and the production of natural aggregate as a functional equivalent of recycled aggregate produced in the circular scenario. LCA results show a 4 times lower impact on GWP in the case of circular scenario.

In the case of waste steel, the circular scenario refers to recycling or reuse, while landfilling and production of primary steel to compensate for wasted steel are considered in the linear scenario. The reuse scenario shows 19 times lower GWP than the linear scenario. The recycling scenario shows a higher GWP impact than the reuse scenario, but it is still 4.6 times lower than in the linear scenario.

In the case of waste wood, the circular scenario refers to wood recycling and the production of recycled particleboard. Waste wood landfilling and the production of particleboard from primary wood are considered in the linear scenario. The circular scenario shows a 6 times lower GWP than the linear scenario.

Conclusions

The environmental benefits of circular end-of-life treatment practices (recycling, in the case of steel also reuse) were confirmed compared to linear practices for three CDW fractions. Attention was given to Global Warming Potential (carbon footprint) expressed in kg of emissions equivalent to CO_2. Further research should also consider other CDW fractions and evaluate additional environmental impacts, especially the Abiotic Depletion of minerals and metals. This is related to another crucial aspect of the circular economy, such as resource efficiency.

Keywords: LCA, concrete, steel, wood, global warming potential

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Social Impacts of Circular Economy

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Resource and energy consumption continues to increase globally, and even technological progress has not been able to reduce the environmental impact of increasing consumption. Slovenia's per capita consumption of materials is in line with the EU average, and Slovenia's resource and energy efficiency is below the EU average (Slovenia Development Strategy 2030, 2017). Slovenia is aware of the urgency of the transition to a circular economy, but the transition is slower than we would like due to unclear legislation and negative attitudes of the wider society towards waste. When measuring the social responsibility of investments (using the SROI method) and their impact on sustainable development goals based on the principles of reuse and the circular economy, waste reduction and understanding how the circular economy works are fundamental starting points (studioKroG). Focusing on reuse of materials means identifying and quantifying the waste avoided by reusing materials and analysing how this approach contributes to reducing the need for new resources and minimising the negative impact on the environment.

Keywords: waste, reuse, circular economy, sustainable development, social innovation

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Circularity of Alkali-Activated Materials: Case Study Using Rock Wool as a Precursor

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Alkali-activated materials (AAMs) are being researched as a sustainable alternative to conventional building and civil engineering industry products (cement, mortar, concrete, and ceramics). Last are made from raw materials and at high temperatures (above 1000 °C), while AAMs need only non-crystalline sources of Si and Al, which dissolve in liquid alkali and form an aluminosilicate network at temperatures below 100 °C. However, AAMs have several issues:

(i) Waste materials can contain heavy metals and other hazardous species which might not get immobilized in AAM,
(ii) If the molar ratio of amorphous elements of alkali metal to amorphous Al is not equal or below 1, efflorescence will take place in AAM and cause deterioration of the product,
(iii) If also alkali earth metals dissolve and interact with the aluminosilicate network, efflorescence can get additionally enhanced (when precalculation is done only on metal alkali elements),

(iv) If from precursor is "used" already everything that could form the aluminosilicate network in AAM, AAM after its end-of-life can not be used again as a precursor in alkali-activated synthesis, but can be used only as an aggregate or go into an acidic reaction chain.

However, this study focuses solely on the potential of circularity of AAMs that theoretically do not lead to efflorescence (Horvat and Ducman, 2019) by following early compressive strength, chemical (FTIR) and mineralogical (XRD) evaluation, as also thermal stability (TG) of AAMs compared to the precursor.

Therefore, AAMs were prepared from rock wool (milled and sieved below 63 μm) and Na-silicate solution (Geosil, 344/7, Woelner, Ludwigshafen, 16.9 m% Na_2O, 27.5 m% SiO_2) in a linear, circular and hybrid model:

(i) The linear model was done as a one-step synthesis (as a reference) where the optimal ratio of alkali to precursor, that should not be exceeded, was calculated from XRF and XRD performed on rock wool: mass ratio of rock wool to alkali was 1 to 0.5, respectively. This ratio was defined as the limit value of the alkali.

(ii) The circular model was simulated as a cycled-stepwise synthesis, where in every cycle 25 m% of the limit value of the alkali was added to in the (1st cycle) rock wool, and in (every next cycle) to the microwave-dried and milled AAM from the previous cycle, until the sum of added alkali was equal to used alkali in the linear model.

(iii) The hybrid model was performed as a one-step synthesis, where the addition of alkali was 25, 50, and 75 m% of the limit value of alkali in the linear model. Although all hybrid mixtures could be used further in upcycling, they were used as a reference to counterpart AAMs prepared in the circular model.

Moulded slurry from the linear model (prisms measuring 2×2×8 cm^3) and pressed "wetted-aggregates" (cylinders with a diameter of 3 cm, the mass of the pressed material 25 g, applied force 10 kN) were cured at 70 °C for 1 d. The mechanical performance of 1-day-old samples indicated the superiority of the hybrid model over other models.

Keywords: fly ash, slag, alkali-activated materials, microwave irradiation, circular economy, sustainability

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Predicting Effluents From Glass Melting Process for Sustainable Zero-Waste Manufacturing

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Slovenia's leading glass producer is advancing sustainability by reintegrating Selenium dioxide (SeO_2)-laden dust, a byproduct of their glass melting process, back into production. SeO_2 is crucial for producing extra white flint glass, ensuring high transparency and colorless glassware, but its volatility at melting temperatures leads to significant emissions captured by dust filters. SeO_2-rich dust is toxic which requires costly and environmentally taxing disposal.

Filter dust can be re-used as a raw material, but a precise SeO_2 content must be known for effective batch calculation. The determination of selenium content is traditionally done by chemical analyses at external institutes abroad, which is time-consuming, expensive and poses health risks to laboratory personnel. The amount of selenium in dust is highly dependent on the manufacturing conditions, since different factors, such as glass temperature, glass pull rate and others significantly affect the evaporation of SeO_2 from glass melt. To transform this challenge into an opportunity, we have developed a predictive model to accurately estimate SeO_2

content in each bag of filter dust, facilitating its reuse as a raw material. Given the different time scales of process monitoring—continuous one-minute sensor readings versus longer intervals for SeO_2 measurements—the predictive model needed to address these disparities effectively.

We used Monte Carlo simulations to handle the variability in process parameters, enabling the development of robust predictive models despite a limited data set. This methodology averaged process parameters over dust sampling durations, ensuring accurate predictions of SeO_2 concentrations. A crucial aspect of modeling was the use of correlation matrices, which preserved the existing inter-parameter correlations. The presentation will detail the data collection, preparation, and simulation processes, highlighting how these predictive models allowed a successful trial where all produced filter dust was recycled into the manufacturing cycle, achieving full circular production within a certain time period.

The implications of the approach extend beyond glass production, offering a modeling technique for different industries, where disparate time scale measurements and process uncertainties are common. This approach not only reduces raw material costs and ecological impact but also enhances overall process sustainability.

Keywords: predictive modeling, glass manufacturing, circular industry, zero-waste production, filter dust, monte-carlo simulations, correlation matrix, continuous manufacturing

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Dependence of Dehydration, Efflorescence and Thermomechanical Behaviour of Alkali-Activated Waste Glass Wool on the Power Level of Microwave Irradiation

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Building and civil engineering consumes yearly almost 70 $m_{\%}$ of the mass of Mount Everest, creates more than 30 $m_{\%}$ of global waste, and produces approximately 40% of man-caused CO_2. Therefore, alkali-activated materials are being researched as a future sustainable alternative to conventional building industry materials (cement, mortar, concrete, and ceramics). Namely, alkali-activated materials can be made solely from waste material and at lower temperatures. The only requirement from the waste material is that it contains enough Si and Al in the amorphous content, like glass wool (GW).

GW is a fibrous material that consumes at the end of its use a lot of space in landfills due to its low density, therefore, using waste GW as the source of Si and Al in alkali activation for building products is an ideal solution. However, the dissolution of the amorphous fibrous material is not complete and the addition of alkali results in non-desired efflorescence, i.e., crystalline salt formation leads to the deterioration of the material, which is for the load-bearing building products dangerous.

Mitigation of efflorescence can be achieved chemically or physically by: (i) keeping the molar ratio Al to 1st group of the periodic system above (or equal) 1 because not all Al will dissolve, or by (ii) complete removal of water.

Therefore, pulverized waste glass wool was mixed with Na-silicate solution (Geosil, 344/7, Woelner, Ludwigshafen, 16.9 m% Na_2O, 27.5 m% SiO_2) in 3 mass ratios: 1 to 0.5, 0.8 and 1 for GW, which all had tendency to lead to efflorescence. Moulded slurries (prisms measuring 2×2×8 cm^3) were cured at 40 °C for 6 d. On day 7, prisms were demoulded and treated further: one-third of the samples was irradiated with microwaves at 1000 W, the second third at 100 W, both until complete dehydration, and the last third was left to evolve further at room conditions as a reference. All prisms were cut vertically into 2×2×1 cm^3 cuboids which were kept at different conditions after day 14:

(i) vacuumed-sealed in a plastic bag and kept at room temperature,
(ii) exposed to 100 % moisture and kept at room temperature,
(iii) exposed to room conditions,
(iv) fully dipped in the distilled water and kept at room temperature,
(v) kept at 70 °C and normal pressure.

The instant influence of microwave dehydration was evaluated according to the changes in the geometrical density due to an increase in porosity, i.e. the higher the irradiation power, the more rapid increase of the pressure inside the irradiated sample, the shorter the time to full dehydration and the larger the cracks in the sample, followed by a decrease in compressive strength measured on the prisms and cuboids. Hence, the method is not useful to solve the efflorescence issue of chemically not optimal mixtures for building industry products, but can be used for evaluation of the time-evolution of the material, if the material is fully dehydrated at

selected times and further kept in a waterless environment, to remain frozen-in-time by hindering diffusion and chemical reactions.

Keywords: microwave irradiation, alkali-activated materials, glass wool, rapid dehydration, efflorescence mitigation, temporal immobilization of reactions

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Development and Characterization of LECA Geopolymers

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In the recent years, a wast amount of research has been dedicated to the development of sustainable building materials that could replace traditional concrete. Geopolymers, a sustainable alternative, offer high mechanical strength and a low carbon footprint. This study aims to develop and analyze various formulations of lightweight expanded clay aggregate (LECA) geopolymers, to evaluate their mechanical and physical properties. Different geopolymer mixtures were prepared using an alkaline activator (10 molar sodium hydroxide), sodium silicate, and fly ash, with different ratios of LECA and aggregate. The prepared geopolymers were tested for compressive and tensile strength, thermal conductivity, and microstructural

properties using scanning electron microscopy (SEM) equipped with Energy-Dispersive X-ray spectroscopy (EDX).

The results demonstrate a positive impact of LECA on the thermal insulation properties of geopolymers. Specifically, the thermal conductivity decreased from 1.147 W/mK to 0.384 W/mK as the LECA content increased from 0 % to 100 %. However, this increase in LECA content negatively affected the compressive strength, which dropped from 63.66 MPa to 17.31 MPa. The tensile strength increased with higher LECA content, rising from 7.279 kN/mm to 8.718 kN/mm. The study found that LECA is a promising component for developing sustainable geopolymers with improved desired characteristics.

Future studies will concentrate on optimizing formulas and analyzing geopolymers' long-term durability and resistance to varied environmental conditions.

Keywords: geopolymer concrete, LECA, light weight aggregate, fly ash, CO_2 reduction

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Effects of Concrete Composition on Shrinkage –Incorporating Polyethylene Glycol as a Self-Curing Agent

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Concrete is the most extensively utilized construction material globally, renowned for its superior compressive strength and cost-effectiveness. Nevertheless, the industrial concrete flooring sector faces one of its most significant challenges - concrete shrinkage.

Firstly, the influence of various components on the magnitude of concrete shrinkage was investigated. Emphasis was placed on the amount of cement paste, fine and coarse aggregate, and the quantity of mixing water. It was found that increased quantities of cement paste result in greater concrete shrinkage. The ratio of fine to coarse aggregate does not exert a significant practical influence on shrinkage.

However, excessive amounts of fine aggregate should be avoided due to their tendency to increase the demand for cement paste, thereby potentially causing greater shrinkage. Additionally, a higher water content in concrete correlates with increased shrinkage.

Secondly, polyethylene glycol (PEG) was added to concrete to act as a self-curing agent. This means it helps concrete retain moisture by reducing water evaporation. It was found that concrete with the addition of PEG maintains a higher moisture content compared to reference. This continuous hydration of cement occurs without needing additional water externally. Moreover, the shrinkage of concrete was reduced, which indicates the relevance of using a self-curing agent in the technology of concrete floors.

Keywords: concrete shrinkage, polyethylene glycol, self-curing, concrete, concrete flooring sector

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7TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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Evaluation of the Performance of Clay-Based Bricks With the Addition of Co-combustion Ash

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Fired clay bricks are one of the most versatile building materials in the world. Clay for brick production can be at least partially replaced by various secondary raw materials. As clay supplies are limited and already running out in some parts of the world, promoting the circular economy model seems crucial for the future of the brick sector (Zhang, 2013). Firing the mixture of clay and secondary raw materials at around 1000 °C can significantly reduce the leaching of heavy metals from the secondary raw materials (Ukwata and Mohajerani, 2017) what can be of importance also when utilize waste ash in clay bricks production to avoid disposal to landfills, which leads to a reduction in the cost of ash treatment and brick production (Haiying

et al., 2011). As part of the EU project AshCycle - *Integration of underutilized ashes into material cycles by Industry-Urban symbiosis*, ashes from various Slovenian incineration plants were tested for their potential use in fired clay bricks. A screening of ash replacement and firing temperature in the production of extruded bricks was carried out by measuring water absorption, porosity, density, weight loss, shrinkage, flexural and compressive strength and freeze-thaw resistance. Two different clays were used to compare the influence of the selected ash on the performance of the fired samples. The raw mixture for brick production provided by the company Goriške opekarne d.o.o. consisted of clay (48 ma%), marl (50 ma%) and coal particles (2 ma%). However, the presence of marl may affect the ash incorporation mechanism and deteriorate the properties of the fired products. The second mixture consisted of clay without added marl and was provided by the Croatian company NEXE. The pure clay mixture and the mixture with 10 ma% selected Slovenian biomass ash from the co-combustion of brown coal and wood biomass were formed by vacuum extrusion and characterized according to the same procedure as the initial samples. The tests included firing in a gradient kiln, accompanied by water absorption and shrinkage, ceramic-technological tests after firing at 950 °C and the evaluation of freeze-thaw resistance. The fired bricks without marl and ash exhibited lower compressive strength than when marl was added to the raw mix. In contrast, the mixture without marl showed slightly higher compressive strength when 10 ma% ash was incorporated into both raw mixtures. However, this mixture had a high water demand and a very high plasticity. The microstructural evaluation provided some further insights into the influence of the ash admixture on clay based products.

Keywords: fired clay bricks, waste ashes, raw mixture, ceramic-technological tests, freeze-thaw resistance

Acknowledgement

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The Development of Sustainable Fiber-Based Moulded Pulp Protective Packaging From Invasive Plant

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Expanded Polystyrene (EPS) has long been a standard in protective packaging due to its excellent cushioning properties and lightweight nature. Despite its protective advantages, EPS poses significant environmental challenges due to its bulkiness and low recycling rates. In response to these challenges and due to regulatory requirements, the development increasingly turned to fiber-based solutions, including corrugated board inserts, fiber foams, and biopolymer fiber composites, as more sustainable and recyclable alternatives.

While these fiber-based options are more environmentally friendly, the overuse of cellulose fibers from wood sources can still strain the environment. A promising solution to this dilemma is the use of fibers derived from invasive alien plants. These plants, known for their negative impact on biodiversity and economic damages such as riverbank degradation, can be repurposed into fiber for packaging production,

thereby mitigating their harmful effects while providing a sustainable resource for packaging materials. The LEAP project (LEarning and demonstration Alliance for designing and manufacturing sustainable industrial Packaging from alternative lignocellulosic biomass) addressed exactly this issue by developing the process of laboratory prototyping fiber-based protective packaging specifically for household appliances that could potentially substitute EPS packaging. Faced with a shortage of virgin wood fibers, the project explores the substitution of these fibers with alternative sources, particularly from invasive plants such as Japanese knotweed. This approach not only mitigates the negative impact of these invasive species on biodiversity and economic damage, such as riverbank degradation but also provides a sustainable and abundant resource for packaging materials. By utilizing alternative fibers in the production of moulded pulp protective packaging we support circular economy principles by enabling a closed-loop recycling system, preserving biodiversity, and minimizing waste. The shift to fiber-based solutions also aligns with growing regulatory pressures and corporate sustainability goals, enhancing brand reputation and meeting consumer expectations for sustainable practices.

In the presented research the developments of fiber-based molded pulp protective packaging within the LEAP project is presented. The moulded pulp testing samples produced from wood-based as well as alternative fibers (Japanese knotweed) were assessed regarding their mechanical (compression and tensile test) as well as cushioning properties. The results revealed, that the developed samples produced from alternative fibers are comparable to samples produced from wood-based fibers as well as protective packaging prototypes can successfully protect household appliances.

Keywords: protective packaging, EPS replacemnet, invasive plant fibers, moulded pulp, circular packaging

Acknowledgement

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Separation and Optimized Immobilization of Enzymes From *Pleurotus Ostreatus* and *Ganoderma Lucidum* for Sustainable Use

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Introduction

Fungi are well known to contain a plethora of different useful secondary metabolites, from antioxidants, anti-inflammatory metabolites, to enzymes. Two of the most used and researched medicinal mushrooms are *Pleurotus ostreatus*, which is the 2nd most consumed mushroom with many health benefits (Gregori et al., 2007), and *Ganoderma Lucidum*, which was already and still is used for many different health applications even now (Ekiz et al., 2023). In our study, enzyme extracts from self-cultivated fungi were obtained and processed with gel chromatography to get crude enzyme laccase. Magnetic nanoparticles (MNPs) were synthesized, and laccase was

immobilized onto them. Lastly, optimization of immobilization and research of immobilized laccase´s properties were done.

Methods

P. ostreatus and *G. lucidum* were both cultivated on wheat bran for 8 days at 27 degrees. Afterwards, extraction of extracellular enzymes took place with a sodium citrate buffer solution and the obtained extracts being subjected to gel chromatography for separation of enzymes. Total protein concentration determination, as well as enzyme assays were performed, measurements being made with UV-VIS spectrometry. MNPs were synthesized, firstly maghemite with co-precipitation of ferrous and ferric ions in the presence of ammonia, then functionalized and reworked to get aminosilane- and chitosan – coated MNPs. Immobilization was optimized in a thermoshaker with the ability to monitor both temperature and shaking speed.

Results

Optimization of the separation process was studied to obtain our target enzyme laccase, which was successfully immobilized on two types of MNPs, namely aminosilane- and chitosan-coated MNPs. Optimal parameters were 3 hours of shaking at 700 rpm and 20 °C for aminosilane-coated MNPs, the same being the case for chitosan-coated MNPs, with the difference of a 1-hour functionalization with 10% V/V of the crosslinker glutaraldehyde before proceeding with immobilization. Immobilization enhanced crude laccase´s properties, prolonging its activity, stabilizing it, as well as making it reusable and easily removable from the reaction mixture because of the MNPs magnetic properties. Laccase, while immobilized, retained activity at temperatures up to 60 °C and was still active after a month of storage in a refrigerator and at room temperature conditions. Reusability was tested as well, with retaining its' activity for up to 18 consecutive reaction cycles with a half-life after 8 cycles.

Conclusions

As verified with much research, immobilization of enzymes is one of the best ways to enhance and preserve enzymes activity as potential biocatalysts for use in water remediation and other sustainable industrial applications (Kyomuhimbo et al.,2023). Our research showed great potential in laccase immobilized on different MNPs.

Keywords: P.ostreatus, G. lucidum, separation, laccase, MNPs, immobilization

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This research was supported by the Slovenian Research and Innovation Agency (ARIS) within the frame of program P2-0046 (Separation Processes and Production Design), project No. J2-3037 (Bionanotechnology as a tool for stabilization and applications of bioactive substances from natural sources) and project No. L2-4430 (Production, Isolation and Formulation of Health Beneficial Substances from *Helichrysum italicum* for Applications in Cosmetic Industry) and joint project No. BI-TR/22-24-04. The authors acknowledge the use of research equipment for the production of biological substances and their detection, procured within the project "Upgrading national research infrastructures—RIUM", which was co-financed by the Republic of Slovenia, the Ministry of Higher Education, Science and Innovation, and the European Union from the European Regional Development Fund, and the system of downstream processes for performance of obtaining biological substances (Package 21, ARIS).

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Comparative Social Life Cycle Assessment of Beverage Packaging Alternatives

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This study comprehensively assesses the social impacts of beverage packaging systems, focusing on polyethylene terephthalate (PET) bottles, glass bottles and aluminium cans. By leveraging the SOCA database, which provides extensive data on social indicators across various sectors and insights from beverage producers, applied methodology systematically identifies and assesses critical areas within the packaging life cycle that have significant social impacts, such as labour practices and community impacts associated with these packaging alternatives. The functional unit

in the study covers packaging required to distribute 1,000 L of beverages, including labels, caps and various forms of transporting packaging (e.g. corrugated cardboard, trays, disposable foil, wooden EURO pallets). Social impact was quantified using the OpenLCA software tool by applying the Social Impacts Weighting Method. This approach, characterised by its simplicity and effectiveness, enables a nuanced comparative analysis that reveals differences in the social impact of different packaging choices. The findings could aid in decision-making regarding considerations of social risks and opportunities while developing environmentally and socially sustainable packaging solutions.

Keywords: Social Life Cycle Assessment, SOCA Database, Packaging Sustainability, Beverage Industry, Impact Assessment

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Bacterial Nanocellulose Beads: Promising Release Systems

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Introduction

Bacterial nanocellulose (BNC) is increasingly recognized as a versatile biomaterial with numerous applications in functional foods and biomedicine. Its unique properties, including high surface area, biocompatibility, and tunable mechanical strength, make it an attractive candidate for encapsulating and delivering therapeutic agents to specific targets within the body. However, to further optimize its functionality, the synergistic potential of combining BNC with natural bio-extracts has been researched.

Avocado (*Persea americana*) seed extracts (ASE) are known to contain a rich array of phytochemicals, including phenolic compounds and flavonoids. These bioactive constituents have been extensively studied for their various health-promoting properties, including antioxidant, antimicrobial, and enzymatic activities (Kupnik et

al., 2023). In particular, their ability to combat bacterial growth makes them valuable candidates for enhancing the antibacterial capabilities of BNC-based drug delivery systems (Kupnik et al., 2024).

Therefore, we aimed to develop BNC-based delivery systems that effectively exploit the therapeutic potential of avocado seed extracts.

Methods

The production of BNC beads was performed using Hestrin and Schramm production medium under dynamic conditions by *Komagataeibacter xylinus*. ASE was obtained via ultrasound-assisted extraction using water as the solvent. BNC beads were subsequently enriched with ASE and their antibacterial activity was tested against Gram-negative and Gram-positive bacteria. The release of the ASE from BNC beads was determined spectrophotometrically.

Results

The results of the research showed successful production of antibacterially active BNC beads enriched with ASE, which represents promising immediate and sustained release systems.

Conclusions

Enriched BNC beads promise advanced biomaterial-based drug delivery and combat bacterial infections with innovative and sustainable approaches.

Keywords: bacterial nanocellulose, beads, avocado extract, release, antimicrobial activity

Acknowledgement

This research was supported by the Slovenian Research and Innovation Agency (ARIS) within the frame of Program P2-0046 (Separation Processes and Production Design), P2-0424 (Design of novel nano/material properties & applications), Project No. J2-3037 (Bionanotechnology as a tool for stabilization and applications of bioactive substances from natural sources), L2-4430 (Production, Isolation and Formulation of Health Beneficial Substances from *Helichrysum italicum* for Applications in

the Cosmetic Industry), and Young Researcher ARIS Fellowship Contract No. 2187/FS-2019. The authors acknowledge the use of research equipment for the production of biological substances and their detection, procured within the Project "Upgrading national research infrastructures - RIUM", which was co-financed by the Republic of Slovenia, the Ministry of Higher Education, Science and Innovation, and the European Union from the European Regional Development Fund, and the system of downstream processes for performance of obtaining biological substances (Package 21, ARIS).

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Incorporation of Nanocellulose Into a Biopolymer Matrix to Improve Mechanical Properties

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Synthetic polymers are versatile materials that have become an integral part of our daily lives. One of their biggest disadvantages is the long-term decomposition process, the other is their extraction from non-renewable raw material resources. In addition to exploring ways to recycle plastic waste, research has recently focused on the development of biopolymers that would reduce the harmful effects on the environment. Increasingly popular biopolymer worldwide is polylactic acid (PLA), which is produced by fermentation of carbohydrates. A second important group of biodegradable polymers are polyhydroxyalkanoates (PHA). The best known form of low molecular weight PHA polymers is poly(3-hydroxybutyrate) (PHB), which is synthesized by bacteria-controlled fermentation processes. The third polymer is poly(vinyl alcohol) (PVA), a water-soluble and biodegradable polymer. All groups of degradable polymers have a high market potential in the bioplastics sector, but some of their properties such as fragility, low temperature resistance, high vapor

permeability and low viscosity limit their wider use. One of the solutions to improve these properties is the incorporation of nano-reinforcing elements.

A good example of such additives are cellulose nanofibrils (CNF), which are usually obtained from wood and whose physical, chemical and mechanical properties far exceed those of cellulose fibers. Because the mechanical properties of CNF are comparable to those of other technical materials (glass, aramid, Kevlar fibers), they are suitable as a reinforcing material for the reinforcement of various polymer bases.

The aim of this contribution is to give an overview of the research work on the production of different types of cellulose nanofibrils and their application as reinforcement in three different biopolymers. Lignocellulose nanofibrils (LCNF) were prepared directly from wood by treatment with maleic anhydride and high-pressure homogenization, while TEMPO ((2,2,6,6-tetramethylpiperidin-1-yl)oxyl)-mediated oxidation of cellulose pulp and high-pressure homogenization was used to produce so-called TEMPO cellulose nanofibrils (TCNF) with increased carboxyl content. The third type of chemically modified nanocellulose were acetylated cellulose nanofibrils (ACNF) with a non-polar acetyl group on the surface of the CNF. In the production of biopolymer nanocomposites based on cellulose nanofibrils, the problem of inhomogeneous distribution of the reinforcing phase on the polymer base arises, which affects the quality and durability of the resulting materials.

Our study addressed the production of green PVA/CNF, PLA/CNF and PHB/CNF biocomposites using unmodified and modified CNFs. The aim was to find the right ratio between the two components in order to obtain composites with improved mechanical and thermal properties and better water resistance. The biocomposites produced were characterized using Fourier transform infrared spectroscopy (FT-IR) and scanning electron microscopy (SEM). The interactions between the components and the effects of these interactions on the properties of the final biocomposites are discussed.

Keywords: nanocellulose, TEMPO mediated oxidation, acetylation, properties, bionanocomposites PLA; PHB; PVA; mechanical properties

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The Hospital-Specific Pharmaceuticals Measurements in Wastewater

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The insidious infiltration of pharmaceutical waste, especially from hospitals, may pose a substantial threat to the environment (Thakuria et al., 2024). Their presence in the water cycle has raised concerns among the professional public regarding possible risks to human health. Routine drinking water monitoring programs do not include monitoring the presence of pharmaceutical products, as is the case for microbiological and chemical parameters. Thus, data on the occurrence of pharmaceuticals in water are the results of various studies, which report that concentrations of pharmaceuticals in surface and groundwater are usually lower than 0.1 µg/l, and concentrations in drinking water are generally below 0.05 µg/l (World Health Organization, 2012). Standardizing the protocols for sampling and analysis of pharmaceutical agents would facilitate data comparison (World Health

Organisation, 2012). In the frame of the common project, the chemical analysis of pharmaceutical pollutants in Austrian drinking water and hospital wastewater was performed. The hospital-specific pharmaceuticals were selected, and their concentrations in a rehabilitation clinic wastewater were determined. Drinking water samples were taken once a month, for two consecutive months. Wastewater was sampled continuously for 2 months, where samples were taken once a week. Secondly, the chemical analyses were performed in cooperation with the National Laboratory for Health, Environment and Food in Maribor using high-resolution liquid chromatography and mass spectrometry (HPLC-MS/MS or HRMS). The results showed that the quantities in drinking water were low, under the limit of quantification, and it is unlikely to pose risks to human health. On the other hand, the occurrence of some pharmaceuticals in wastewater samples was confirmed in a few samples. The concentrations of caffeine and analgesics (paracetamol, naproxen) were found in significant concentrations in certain wastewater samples, thus it is a challenge in assessing potential human risks. Paracetamol and naproxen are known to accumulate in the aquatic environment and have been detected in surface water, wastewater and drinking water worldwide (Wu, et al., 2012). A systematic study will contribute to further understanding of the occurrence, transport, and circulation of pharmaceutical agents in the environment.

Keywords: hospital wastewater, pharmaceuticals, HPLC-MS/MS, pollutants, drugs

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Hydrolysis of Polycarbonate in Subcritical Water

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In recent years, the chemical recycling of waste polymers has attracted considerable attention as a method of recovering valuable products from plastic waste (Helmer Pedersen and Conti, 2017). Polycarbonate (PC), an engineering thermoplastic, is increasingly being utilized in a variety of applications. Its popularity, particularly in outdoor applications, is increasing due to its favourable properties, such as excellent transparency, low density and high mechanical strength, making it one of the most widely used engineering thermoplastics (Weibin et al., 2009). Subcritical water provides an optimal medium for various chemical reactions, including the degradation of various plastics (Ikeda et al., 2008).

In this study, the decomposition of virgin polycarbonate (PC) in subcritical water was performed to determine the optimal reaction conditions (temperature and time) for the recovery of valuable products. The experiments were conducted in a batch reactor at temperatures ranging from 250 °C to 350 °C and for a duration between 5 min and 120 min. The decomposition of PC into valuable products such as bisphenol A (BPA) monomer, 4-isopropylphenol (4-IPPH) and phenol was successfully achieved in subcritical water. The investigation of the influence of the

process parameters (temperature and time) showed that the maximum yield of the oil phase (97.7 %) was achieved at a reaction temperature of 350 °C and a reaction time of 15 minutes. It was found that the BPA monomer exhibited poor stability in subcritical water and was rapidly degraded into valuable chemicals such as 4-IPPH and phenol at higher reaction temperatures (300 °C and 350 °C) and longer reaction times. The results of the study show that the choice of process parameters is of crucial importance, as they influence the course of the reactions and thus the type of degradation products and their yields.

Keywords: polycarbonate, subcritical water, chemical recycling, hydrolysis, BPA

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New Fair and Circular Business Models Creating Value From Agricultural By-Products: C4B Project

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The ongoing C4B project, funded through the Horizon Europe research and innovation programme, is performing with the general objective to accelerate the development and economic sustainability of European rural communities. Specifically, the project aims to facilitate the involvement of primary producers in the circular rural bioeconomy through fair and sustainable business models for new bio-based value chains.

By joining expertise and competences of 11 EU multidisciplinary partners and by engaging stakeholders with a multi-actor approach, 9 selected case studies will validate a new holistic research framework advancing the understanding of bio-based value chains valorising agricultural by-products (wine, cereals, wood, apple, potato, peatlands).

Based on this knowledge, currently being developed by the involved research centres, sustainable C4B business models will be tested for their applicability, scalability and replicability in different business environments and geographical areas, also through an Open Call. Such business models will take into account technological, business, social, fairness, ownership and contractual dimensions, as well as the environmental, economic and social impact assessment.

The following figure summarizes C4B approach:

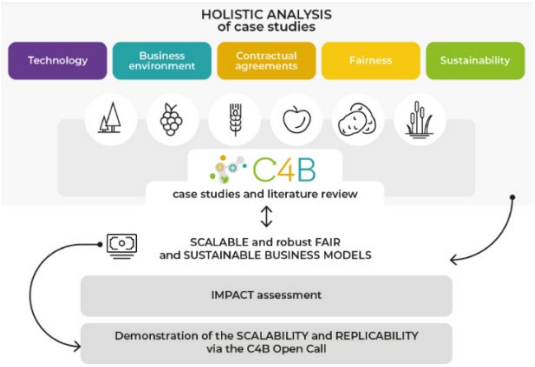

Figure 1

This project will favor the balance of power and profits across novel bio-based value chains and will enhance the cooperation among farmers, foresters and industry, eventually stimulating the uptake of the new business models and accelerating the spread of a circular rural bioeconomy across Europe.

C4B started on 1. 1. 2024 and will be completed within 31. 12. 2027. The partnership involves the following organizations: CIAOTECH Srl (IT), Innovation Engineering Srl (IT), PNO Innovation SL (ES), APRE Agenzia per la Promozione della Ricerca Europea (IT), Fondazione Agrifood & Bioeconomy FVG (IT), Biofuel Region (SE), Cluster of Bioeconomy and Environment of Western Macedonia - CluBE (HE), University of Hohenheim (DE), Wageningen University (NL), Wageningen Research (NL), Leitat (ES). For more information: https://www.c4b-project.eu/.

Keywords: bioeconomy, circularity, business models, bio-based value chains, fairness, rural sustainable development

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Kansai Helios – Measuring the Environmental Impact

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Kansai Helios is a European group of coating companies. Our portfolio of products is highly diversified, starting from synthetic resins to various types of coatings: waterborne, solventborne and powder coatings. Our goal by 2030 is that at least 80 % of our R&D projects will be related to sustainable products. To support this goal, we have developed an internal sustainability index toolbox to help our R&D engineers determine sustainability of Kansai Helios products and processes.

Further, we have calculated cradle-to-gate product carbon-footprints (PCF) of more than 100 our products this year. We use this strong tool to meet internal demand (where we stand and where can we do better in terms of PCF) as well as to supply our customers with this, much desired, data. The contribution of raw materials to the PCF value is typically more than 80 %. In-bound transport and internal transport among our production sites contribute up to 8 % to the total PCF value.

Through deep cooperation with our purchasing team and suppliers, we have collected almost 600 PCF data of our raw materials. Where the primary data is not available, we use data from e.g. EcoInvent 3.10 and CEPE databases. Bio-based or partly bio-based raw materials may have important impact on lowering PCF value.

In our effort to obtain deeper knowledge on our products' impacts and to provide our customers with more details on environmental impacts of our products, we have cooperated with an external expert team of LCA practitioners to build our internal capacity to perform full cradle-to-gate LCA analyses of our products.

Several companies in Kansai Helios group have been regularly evaluated by EcoVadis in recent years and have been awarded Gold level sustainability ratings.

Keywords: sustainability, product carbon footprint PCF, Life Cycle Assessment LCA, sustainability index, coatings, chemical industry

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Sewage Sludge Drying and Heating Valorization

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This study examines an innovative and sustainable approach for converting sewage sludge, initially containing 80 % water, into reusable biochar through a series of drying and pyrolysis processes. The process begins with drying the silt at a flow rate of 1 tonne per hour. This critical step reduces the water content of the silt from 80 % to a manageable 12-15 %, making it suitable for subsequent processing. The drying phase utilizes biochar derived from the pyrolysis stage, effectively using the energy from the biochar to drive the moisture reduction process. This integration of energy sources not only optimizes the efficiency of the drying process but also significantly reduces the overall energy requirements.

Once the silt is adequately dried, it undergoes pyrolysis. Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen, breaking down organic materials to produce biochar, along with other by-products such as gases and oils that are burned before condensation. In this process, the biochar produced can be reused up to eight times. Furthermore this reusability is a key aspect of the process's

sustainability, as it maximizes the utility of the biochar, reducing the need for continuous raw material inputs and minimizing waste.

The heat generated during both the drying and pyrolysis stages is another critical component of this sustainable process. This heat is not wasted but is instead captured and reused within the system. By recycling the heat, the process achieves a higher energy efficiency, significantly lowering the energy input required for drying and pyrolysis operations. This closed-loop approach ensures that the energy generated from the biochar and other by-products is fully utilized, contributing to the overall sustainability of the process.

All side products are burned on-site, converting into energy that can be fed back into the system. This combustion of by-products ensures that the process not only minimizes waste but also maximizes energy recovery. By converting all outputs into useful energy, the system achieves a high degree of resource efficiency.

The integrated process of drying and pyrolysis described in this study represents a significant advancement in sustainable waste management and resource recovery. By reducing the water content of silt from 80 % to 12-15 %, using energy derived from pyrolysis-produced biochar, and ensuring the reusability of biochar up to eight times, the process demonstrates a high level of efficiency and sustainability. After multiple usage of carbon, the sewage sludge acumulates on the carbon, which is then burned in the process of pyrolysis. The reuse of heat generated during the process further enhances its energy efficiency, while the combustion of pyrolysis by-products ensures maximum energy recovery and minimal waste generation.

In conclusion, this study presents a comprehensive and sustainable method for transforming sewage sludge into reusable biochar, with significant implications for waste management and resource recovery. The process not only reduces the environmental impact of silt disposal but also provides a valuable source of reusable biochar and energy, contributing to the circular economy. The innovative use of biochar for drying, the high reusability of biochar, and the efficient energy recovery mechanisms highlight the potential for widespread application of this process in various industrial settings.

Keywords: drying, sewage sludge, pyrolysis, carbon, biomass

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Eco-Friendly Bioleaching: Innovative Technology for Extracting Critical Raw Materials From the WEEE

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The escalating demand for resources to fuel the growth of innovative technologies and products, particularly in producing electrical and electronic equipment (EEE), has led to a rapid increase in waste electrical and electronic equipment (WEEE, or e-waste). E-waste is currently the fastest-growing waste stream globally, expanding at an annual rate of 3-5 % (Liu et al., 2022; Copani et al., 2019). The OECD predicts global materials demand will rise from 79 billion tonnes today to 167 billion tonnes by 2060 (Blengini et al., 2020). The Global E-waste Monitor 2024 reports (Baldé et al., 2024), that e-waste reached 62 million metric tons in 2022, an 82 % increase since 2010, with only a small fraction being recycled in an environmentally sound manner. Of this, only 22.3 % has been documented, collected, and recycled environmentally soundly. This situation underlines the urgent need for effective e-waste management strategies. In Europe, 13.5 million tonnes of electrical and electronic equipment are marketed annually, generating 4.9 million tonnes of e-waste, less than 40 % recycled, with an average of 11 kg collected per person(EC ENV, 2024). E-waste contains hazardous and valuable materials, including critical raw materials (CRMs) and rare

earth elements (REE), making recycling complex. Properly managing and recycling e-waste is not just a necessity, but a crucial step towards supporting the EU's 2050 climate neutrality targets under the EU Green Deal (2019) and contributing to the transition to a circular economy and decarbonisation. Printed circuit boards (PCBs), a crucial component of many electronic devices, contain valuable metals and toxic substances, presenting significant recycling challenges (Zhao et al., 2023; Gulliani et al., 2023). The urgent need for effective e-waste management is underscored by its severe risks to human health and the environment (Perkins et al., 2014; Jain et al., 2023). This necessitates the development of innovative strategies for raising awareness, collection, pre-treatment, recycling, and reusing products. Society and researchers are urged to develop novel technologies for e-waste treatment and CRM recovery complexities. Sustainable PCB and mobile phone treatment through innovative processes like bioleaching can address environmental and economic challenges while fostering a value chain and employment in the recycling sector in the EU RIS countries. Bioleaching, a biotechnological process using microorganisms to extract valuable metals from e-waste (Pathak et al., 2017), has gained attention as an environmentally friendly alternative to traditional methods such as pyrometallurgy and hydrometallurgy. PCBs are rich in metals like copper, cobalt, nickel, zinc, gold, silver, etc., making them prime candidates for bioleaching. Microorganisms like *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* are particularly effective due to their ability to oxidise iron and sulfur compounds, respectively (Mostafavi et al., 2018). Our research on laboratory scale under the EIT RawMaterials WEEE-NET9 project on bioleaching involves multiple phases: sample preparation for chemical analysis, preservation of culture mediums for the microorganisms, and the bioleaching process itself, which takes a maximum of 25 days. This method is noted for its simplicity, effectiveness, low cost, and eco-friendliness, generating less secondary waste and facilitating metal recovery. Bioleaching involves converting insoluble metallic compounds into soluble forms that microorganisms can transfer into solution. Results of testing: valuable metals extracted through this process include copper, nickel, lead, zinc, chromium, cobalt, and palladium. Parameters like particle size, pH, temperature, pulp density and bacterial growth affect bioleaching efficacy. With the WEEE-NET9 project, taking into account the Critical Raw Materials act (2024) and the European agenda on the provision of critical and strategic raw materials, we contribute to the EU's goal to provide at least 25 % of CRMs from recycling and at the same time at least 65 % of CRMs from own production.

Keywords: WEEE, e-waste, circular economy, critical raw materials, innovative technologies, bioleaching

Acknowledgement

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Demonstration and Application of the Geopolymerization Technology for Waste Processing – The GEORIS Project

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In the GEORIS project - *Innovative technologies for waste processing in ESEE Region* - a novel geopolymerization technology that process industrial waste and by-products to innovative construction materials has been transferred to the ESEE region (EIT RawMaterials, 2022). A demonstration of the innovative possibilities and application of developed technology has been conducted to manifest the competitive advantages and facilitate its adoption. Pilot sites in Slovenia, Greece and Poland were set where mineral waste and by-products with geopolymers as a binder are used to reveal the appropriateness of this technology for everyday use. The effort was focused on construction companies, industrial waste providers and public

authorities responsible for infrastructure development, adopting green criteria in their purchasing policy.

For the demonstration two waste streams – steel slag and bauxite residue were valorized for the production of pavement blocks and fire-resistant panels

A technical analysis on the materials produced as well as an economic analysis were performed to more accurately calculate the financial benefits of the technology (Georis, 2024).

Bauxite residue as a component for porous fire-resistant panels revealed a good potential to be used in internal wall tiles, while developed materials from bauxite residues for pavement blocks showed optimal performance and have been used to pave a parking area of 25m^2 in Aspra Spitia, Greece. Pavement blocks from steel slag are still in test phase. Both pavers (from bauxite residue and steel slag) are currently under validation and demonstration in relevant environment (TRL 5-6).

Economical calculations on small scale laboratory production confirmed that tiles or panels produced from waste slag or bauxite residues compete with concrete or insulated metal panels available on the market. Nevertheless, a careful costs optimization in any pilot production is necessary to determine economic valorization precisely.

The general conclusion of this study is that geopolymerization technology is convenient for producing construction materials from secondary raw materials, while successfully competing with standard products. Next steps are to define standardization policy and upscaled technoeconomical assessment of the materials. Our strong motivation is positive feedback from technology adopters in the region, interested in the technology, expressed during capacity building workshops.

Keywords: georis, geoplymerization, waste proccessing, novel technology, construction materials

Acknowledgement

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Rhenium Catalysed Production of Bio-Based Acrylates From Glyceric Acid

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Acrylic acid and acrylate esters are essential monomers in the polymer industry, traditionally synthesized from a fossil resource propylene. To foster sustainability and reduce dependency on fossil fuels, renewable biomass-based routes are being developed for the production of acrylic acid. A promising approach involves producing bio-based acrylic acid and its esters from glyceric acid, which is derived from glycerol oxidation, a by-product of biodiesel production (Sun et al., 2017). This innovative process for the heterogeneously catalysed deoxydehydration (DODH) of glyceric acid and its derivatives has been recently submitted as a patent application by our research group (PCT/EP2023/070258). The core step in this innovative pathway is using rhenium supported catalysts (Hočevar et al., 2021).

In the study we explored different molecular and supported Re catalysts regarding their catalytic behaviour for conversion of glyceric acid. All experiments were carried out in 75 mL high-pressure stainless-steel Parr reactor systems. Different supported

Re were tested (Re/C, Re/TiO_2, Re/SiO_2, Re/Al_2O_3 and Re/H-ZSM-5). Moreover, the influence of reaction temperature was systematically studied as well as the internal gas phase. Different solvents, which can also serve as reducing agents, were used to help understand the DODH mechanism.

The results indicate that carbon is the most effective support for converting glyceric acid to acrylates. Increasing the temperature enhances all reactions, including DODH, hydrogenation, and esterification. Additionally, altering the inert gas and alcohol solvent can shift the reaction towards other products, such as methyl propionate and propionic acid. Overall, the versatility and efficiency of this heterogeneously catalysed process represent a shift toward more sustainable and environmentally friendly polymer production.

Keywords: acrylic acid, heterogenous catalysis, rhenium, deoxydehydration, glyceric acid

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Magnetic Polysaccharide Nanocomposites as Modifiers for Electrochemical Sensors: Influence of the Binding Mode of Quaternized Chitosan

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The presence of antibiotic residues in wastewater has become a major environmental problem, primarily introduced by sources such as wastewater and pharmaceutical production. Even at low concentrations (µg/L or ng/L), these antibiotics can disrupt ecosystems by impairing the reproductive and immune systems of aquatic and terrestrial organisms. In addition, prolonged exposure to environmental antibiotics promotes the development and spread of antimicrobial-resistant bacteria, posing a serious global health threat. Therefore, there is an urgent need for highly

sensitive detection methods, such as electrochemical sensors modified with nanomaterials. Among these, magnetic nanoparticles functionalized with polysaccharides show great potential for improved electrochemical responses. This pioneering study investigates the modification of magnetic iron oxide nanoparticles (MNPs) with quaternized chitosan (qCH), a polysaccharide derivative, using two approaches. In the first method, the MNPs were directly modified with qCH, resulting in MNPs-qCH. In the second method, the MNPs were first functionalized with citric acid (MNPs@CA), followed by the electrostatic attachment of qCH to form MNPs@CA-qCH. The crystal structure of the prepared nanomaterials was confirmed by X-ray diffraction (XRD), and their size and morphology were investigated by transmission electron microscopy (TEM). Infrared spectroscopy identified specific functional groups, while X-ray photoelectron spectroscopy (XPS) provided a detailed elemental analysis. Changes in surface charge were monitored with electrophoretic measurements, mass loss was tracked with thermogravimetric analysis (TGA) and magnetic properties were assessed with a vibrating sample magnetometer (VSM). The results show that the MNPs were successfully modified using both methods and have functional groups that improve antibiotic adsorption and sensing capability. Advanced sensing technologies, especially those using innovative magnetic nanomaterials, have significant potential for the effective monitoring and containment of antibiotic residues in the environment.

Keywords: magnetic iron oxide nanoparticles, quartenized chitosan, magnetic nanocomposite, electrochemical sensor, environmental protection

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Synthesis of Various Magnetic Zeolites for Removing Micro- And Nanoplastics From Water

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The degradation of enormous amounts of plastic waste into micro- (MPs) and nanoplastics (NPs) poses a serious threat to aquatic and terrestrial ecosystems as well as human health. Research into sustainable methods to remove MPs and NPs, such as the use of composites of magnetic nanoparticles (MNPs) and zeolites, is crucial to address this issue. Zeolites have a high adsorption capacity for MPs and NPs, while MNPs enable easy separation and removal of the particles from the water. Our objective was to synthesize composites of MNPs and zeolites that are designed for efficient removal of MPs and NPs from water.

MNPs were synthesized by two methods: i) a co-precipitation method and ii) using a modular flow microreactor systems. Fe^{2+} and Fe^{3+} salts as iron sources were used as reagents and ammonium hydroxide (NH_4OH) as the precipitating agent in co-precipitation method. The aqueous solution containing both Fe^{2+} and Fe^{3+} salts was

held at 80 °C for an hour, while constantly stirred. 25 % NH_4OH was added to the heated solution to initiate the co-precipitation process. For the synthesis of MNPs obtained in microreactor system, acidic solutions of Fe^{2+} and Fe^{3+} ions and a 3 M solution of NaOH were used as reagents and continuously fed into the microreactor with retention time 1.25 min. The results of both methods yielded MNPs with different morphologies, sizes and magnetic properties, which are crucial for the subsequent application of these particles. Two different types of synthetic zeolites, zeolite 4A and zeolite 13X were used to synthesize the composites. The mentioned zeolites have different pore sizes, therefore the effect of pore size on the penetration of MNPs could be observed. The composites were prepared at different pH values. Initially, the composites were produced in a mass ratio of 1:1 if MNPs to zeolite. Later, the mass ratio was varied to 1.5:1 and 0.5:1 to investigate the effects of particle quantity. In the synthesis of the composites the zeolites were immersed in a suspension of previously synthesized MNPs with stirring. The reaction mixture was then stirred for 24 hours at room temperature. The composites were purified with water and ethanol before drying. The synthesized MNPs, zeolites, and composites were characterized by Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA) and dynamic light scattering (DLS).

It was found that the synthesis of the composite is most effective at a pH 7, for the co-precipitation method and at a pH 3.5 for the use of the microreactor system. Therefore, we synthesized composites at this pH with different mass ratios and found that a ratio of MNPs to zeolite ratio of 1:1 is the most efficient, as the composites synthesized at pH 7 and 3.5 with a mass ratio of 1:1 contain the most zeolite and show the potential for efficient removal of MPs and NPs from water, which will be further validated using stimulation solutions.

Keywords: MNPs, zeolites, composites, environmental applications, water purification

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Mining the Future: Bioleaching Waste Electrical and Electronic Equipment (WEEE) for Precious Metals Recovery

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Bioleaching is a bio-based process, besides pyrometallurgy and hydrometallurgy, which employs microorganisms for extraction of metals from various materials, such as electronic waste, municipal waste, red mud, mine tailings, low-grade ores, etc. As a key component of biomining, it aligns with the EU's circular bio-economy agenda, aiming to ensure sustainable supply of critical raw materials. Bioleaching is considered to be a cost-effective and environmentally friendly method that generates lower quantities of hazardous waste. However, it is a relatively slow process that depends on operating conditions, is susceptible to microbial inhibition and is influenced by environmental factors such as temperature and pH. It uses

microorganisms to extract these resources, promoting resource sustainability and reducing the need for traditional mining practices. The most commonly used microorganisms in bioleaching are *Acidithiobacillus ferrooxidans* and *Acidithiosbacillus thiooxidans* (Adetunji et al., 2023; Arshadi et al., 2015).

Microorganisms and metal bearing particles interact in the bioleaching process. Through reactions of oxidation and reduction, acidolysis, complexolysis solid metal forms are converted into dissolved species into the leaching solution. There are many parameters that influence bioleaching, such as pH, temperature, pulp density, bacterial growth and particle size (Arshadi et al., 2019). The entire bioleaching process is more time-consuming and lower recovery of the metal by bioleaching alone is possible, in comparison to other metallurgical process (Erust et al., 2020; Chandane et al., 2019; Awasthi et al., 2016).

The materials on which my research is focusing on are waste electrical and electronic equipment (WEEE) or e-waste (electronic waste). The latest data shows that 50 million tons of e-waste are generated annually worldwide (Habib et al., 2022; Mostafavi et al., 2018). Out of this 4.9 million tonnes are produced in the EU. The improper disposal of e-waste poses a serious threat to both the environment and public health (Pant et al., 2012). The most common elements that can be recovered by bioleaching are Cu, Ni, Zn and Co (Ramanathan et al., 2016).

The aim of this work is also to use and improve bioleaching to achieve best possible recovery of valuable critical raw materials – specifically metals from electronic waste, and to compare this method to pyrometallurgy and hydrometallurgy, also from economic and environmental point of view. We are currently in the process of applying bacteria to mobile phone and PCB samples. The entire process takes 25 days to complete. The biggest changes have been observed in the following elements – Cu, Ni, Pb, Zn, Cr, Co and Pd.

In addition, we have optimized key boundary parameters, such as the liquid-to-solid (L/S) ratio, pH value, selection of bacteria, and leaching conditions (aerobic, anaerobic and addition of oxygen). We have already achieved a certain level of effective extraction for these specific metals, demonstrating positive progress in our research.

Keywords: WEEE, e-waste, critical raw materials, *Acidithiobacillus ferrooxidans*, *Acidithiosbacillus thiooxidans*

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Sheet Moulded Compounds From Waste Polycarbonate-Carbon Fibre Composite Tapes

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The study focuses on the thermo-mechanical characterization of polycarbonate-based sheet moulded composites (SMCs) fabricated using off-cut waste and non-conforming unidirectional (UD) composite tapes. This research addresses the growing interest in thermoplastic (TP) based composites due to their ease of handling, high production suitability, and recyclability. The qualitative and standard tests were performed to examine the thermo-mechanical properties of compression pressed SMCs plates. A hybrid composite (HY-SMCs) was developed by combining non-conforming unidirectional waste tapes in a 50:50 ratio for the top and bottom layers, and core/middle section with randomly oriented platelets. This hybridisation resulted in significant enhancements in mechanical performance, with an 81% to 85% increase in mechanical strength compared to standard aluminium grades and a 120% to 130% increase in tensile and flexural properties compared to conventional SMCs. Fractographic analysis indicated complex fracture behaviours with multimode failures in both SMCs and Hy-SMCs. Furthermore, Non-destructive evaluations revealed re-orientation of platelets during consolidation and localized

voids with increased specimen thickness. The research findings indicate that with further optimisation of consolidation processing conditions and the redesign of the SMC to UD tape ratio, the performance of these composites can be further enhanced.

The current research development aligns with the industrial emphasis on reducing processing waste and signifies a step forward in the sustainable application of TP-based composites. This investigation highlights the potential of TP-based SMCs to replace thermoset-based composites in automotive, sports and aerospace industries due to their superior thermo-mechanical properties and recyclability. Henceforth, demonstrating the TP-based SMCs potential to meet high-performance demands in various industrial applications while promoting recycling and re-conversion of composite materials.

Keywords: thermoplastic composites, carbon fibre, polycarbonate, sheet moulding compounds, thermo-mechanical properties

Acknowledgement

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Phosphorized and Cationized Nanocellulose Fibers as a Surface Modifier for Magnetic Iron Oxide Nanoparticles: A Prospective Nanomaterial for Electrochemical Antibiotic Sensing

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Currently, the main sources of antibiotic emissions into the environment are municipal wastewater, manure and sewage sludge, where they can accumulate. In addition, considerable emissions arise from manufacturing processes and the

disposal of unused antibiotics. There is evidence that certain antibiotics reach concentrations (in μg/L or ng/L) in waters that pose serious risks to wildlife, including direct toxicity (Cristea et al., 2017), (Hrioua et al., 2021). Monitoring these low concentrations is an analytical challenge. In addition, the release of antibiotics into the environment is of concern as it contributes to the development and spread of antimicrobial resistance (AMR), a major global health threat. Therefore, effective analytical monitoring of antibiotic emissions in the environment is crucial, with electrochemical sensors providing a promising solution. However, conventional bare electrodes are subject to limitations, such as sluggish surface kinetics, which compromise their sensitivity and selectivity. In addition, these electrodes often generate broad analytical signals (peaks) (Baig et al., 2019) (Hanko et al., 2019). Recent advances in electroanalytical methods have focused on nanomaterials, particularly magnetic-based materials. However, further research is needed to develop highly functional magnetic-based modifiers for electrochemical sensors.

This study aims to develop magnetic iron oxide nanoparticles (MNPs) functionalized with anionic phosphorylated nanocellulose fibers (pCNFs) and cationic quaternized nanocellulose fibers (qCNFs) containing phosphorus and quaternized functional groups. The aim is to potentially improve the electrochemical sensing performance for antibiotic detection. First, bare MNPs were synthesized by hydrothermal synthesis using iron sulfate salts and subsequently functionalized with pCNF and qCNF. The resulting nanocomposites were characterized by transmission electron microscopy (TEM) to verify the morphology and success of the modification. Further characterization included infrared spectroscopy, electrokinetic measurements of the zeta potential, X-ray photoelectron spectroscopy (XPS) and the evaluation of thermogravimetric and magnetic properties. The results showed the successful formation of functional layers on the MNPs, which can likely improve the adsorption of antibiotics with present functional groups and further the electrochemical sensing. This result indicates that nanocellulose functionalized MNPs are promising as effective modifiers for electrochemical sensors for antibiotics, which is probably related to the improved adsorption ability of the developed nanocomposite.

Keywords: nanocellulose, magnetic-based nanomaterials, surface modification, nelectrochemical sensors, antibiotic sensing,

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Developing Safe and Sustainable Hydrophobic Textile Coating Materials Through Design - Natural Renewable Solutions to Mitigate the Toxicity of Polyfluoroalkyl Substances (PFAS)

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Per- and poly-fluoroalkyl substances (PFAS) are synthetic compounds widely utilized in various industries for their beneficial characteristics, such as hydrophobicity, lipophobicity, chemical inertness, exceptional lubricity, non-stick properties, high fire resistance, resistance to extreme temperatures, and durability against weathering. Despite their advantages, recent studies have revealed that PFAS

compounds exhibit persistent, accumulative, and highly mobile properties that pose environmental risks. (Sharma et al. 2024) Recognizing the toxicity of PFASs, ongoing research in the HE project PROPLANET is investigating alternative options (https://www.proplanet-project.eu/). A significant portion of PFAS compounds is employed in the textile sector. Our in-depth contribution focuses on exploring natural-based hydrophobic coatings for textiles, utilizing materials like natural waxes, fatty acids, naturally occurring polymeric compounds (such as proteins, carbohydrates, aromatic polymers, and natural rubber), and other natural substances. The aim is to create environmentally sustainable methods for applying these coatings to textiles, including relevant modification processes. It critically evaluates the properties and longevity of natural solutions in comparison to PFAS-based coatings, emphasizing the importance of transitioning away from PFAS compounds towards nature-derived alternatives for imparting hydrophobic properties to textiles.

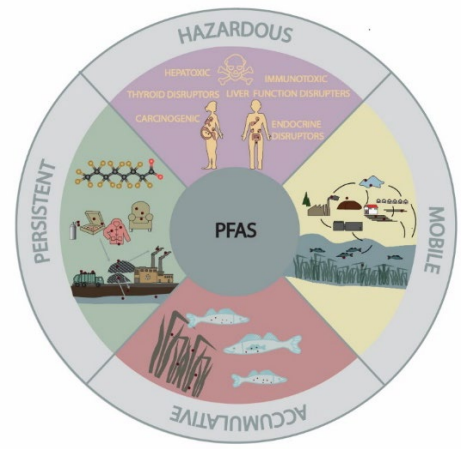

Figure 1: PFAS effect in the environment.

In the keynote lecture the path towards creation of highly hydrophobic (WCA <120°) bio based coating composed of AKD-polysaccharide, chitosan/OSA modified starch coatings and chitosan/wax microcapsules will be discussed.

Keywords: PFAS, Safe hydrophobic coating, SSbD, polysaccharides, textiles

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Selective Enzymatic Ligno-Cellulose Modification and Depolymerization

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The bioeconomy relies strongly on biomass as a renewable resource for materials, chemicals and fuels. The complex polymeric structure of plant cell walls offers advantageous properties for its use as materials, e.g. in construction, because of its mechanical stability and resistance to degradation. Isolated carbohydrate polymers from plant cell walls, such as cellulose and hemicelluloses, can be used in a variety of applications, ranging from food to consumer products to building materials. The highly interconnected, polymeric structure of the cell wall, however, also poses a challenge to the separation of individual components as well as to the isolation of defined chemical building blocks as required for green biorefineries. Fungi secrete oxidoreductases at an early stage of biomass deconstruction to improve the accessibility of plant polymers to fungal hydrolytic enzymes. We are investigating this cascade depolymerization strategy to unravel different polymers without subjecting them to total hydrolysis and to use them in circular applications.

Lytic polysaccharide monooxygenases (LPMO) are a class of endo-acting peroxygenases that are formed in multiple forms by many organisms and cleave various carbohydrate polymers to soften up the cell wall for the separation of constituents (Munzone et al., 2024). The kinetic characterization of LPMOs is a prerequisite to apply their catalytic versatility in industrial processes. To this end, we developed electrochemical techniques in order to (i) study the activity of LPMOs in combination with other enzymes (oxidoreductases and hydrolases) on poplar wood, and (ii) to determine the preferred polymeric substrate of a given LPMO as well as its pH- and temperature-dependent activity, apparent catalytic constants, and turnover stability (Schwaiger et al., 2024). Our results show that LPMOs are highly efficient biocatalysts for the initial depolymerization of cellulose and hemicelluloses operating in the S3 layer of wood cells (Gacias-Amengual et al., 2022). Depending on the intensity of the enzymatic treatment, the polysaccharides are either only slightly modified, providing access points for further chemical modification, or depolymerized into mono- and oligosaccharides for various applications.

Keywords: bioeconomy, biomass, depolymerization, enzymatic activity, hydrolases, modification, oxidoreductases

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Determination of the Maximum CO_2 Sequestration Capacity of Slovenian Waste Ashes Using Thermogravimetry and Calcimetry

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The production of ash from waste incineration or thermal power plants (either based on coal or renewable sources such as biomass ash) is steadily increasing in Europe, but there are environmental concerns regarding solid residues, which are usually landfilled (Abramov et al., 2018). There are several options for utilizing the received or pre-treated waste ash, of which CO_2 sequestration by accelerated mineral carbonation is a promising technology for carbon capture and storage (Li and Wu, 2022). However, the main problem that is important for widespread utilization is to keep the properties of ash, which is a heterogeneous material, constant. Ashes with a high content of Ca and Mg compounds, i.e. those from wood biomass, are promising candidates for sequestration. The high availability of biomass ashes as a by-product of solid fuel combustion is therefore an additional advantage. As part of the EU project AshCycle - *Integration of underutilized ashes into material cycles by Industry-Urban symbiosis*, we analyzed ashes from various incineration plants and determined

their potential for carbon sequestration (Tominc and Ducman, 2023), including various waste ashes from Slovenia. These were exposed to accelerated carbonation conditions in a closed carbonation chamber at a CO_2 concentration of 4 % v/v, high relative humidity (80 %) and temperature (40 °C) until they reached maximum CO_2 uptake. Maximum CO_2 uptake was reached after 7-14 days of carbonation. The amount of CO_2 was quantified by calcimetry (pressure calcimeter) and thermogravimetry.

The process of CO_2 uptake can be significantly influenced by various parameters, e.g. particle size, relative humidity, temperature and CO_2 concentration. Depending on their chemical and mineralogical composition, ashes have shown different sequestration capacities. A high potential for sequestration was found for ashes from wood biomass and from the co-incineration of wood waste and paper sludge, while other investigated ashes showed a lower potential. It was confirmed that in a semi-dry mineral carbonation process the highest CO_2 sequestration capacity, measured in biomass ash, reached a value of 302 g/kg.

The direct use of ash from wood biomass to sequester CO_2 for carbonated building products would therefore be very beneficial in terms of a circular economy, as 70 % of ash from wood biomass is still landfilled.

Keywords: CO_2 sequestration capacity, accelerated carbonation, waste ashes, thermogravimetric analysis, calcimetry

Acknowledgement

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β-Lactamase Encapsulated Metal-Organic Frameworks for Penicillin Degradation

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Introduction

Antibiotics and their uncontrolled abuse of use is posing a serious threat to human health, as well as to the environment. Lately, there has been an increasing focus on biological methods for antibiotic degradation using enzymes, since they can degrade antibiotics due to their excellent catalytic properties, eco-friendly nature and high biocompatibility (Bhattacharya and Khare, 2022). To address these challenges, various strategies have been developed to enhance catalytic performance and increase stability and reusability, with enzyme immobilization onto novel nanostructured biomaterials (Langbehn et al., 2021). Such nanomaterials are metal-organic frameworks (MOFs), which are a versatile group of porous materials known

for their extensive surface area, adjustable pore size, crystalline structure, and wide range of functionalities (Saeed et al., 2024). Therefore, enzyme encapsulated MOFs present a versatile and effective tool for elimination of hazardous pollutants from the environment and utilization for degradation of antibiotics in wastewater systems with high efficiency.

Methods

ZIF-8 nanoparticles were synthesized by the reported method (Chen et al., 2018). Briefly, zinc acetate (20 mmol/L) in water solution was quickly added to 2-methylimidazole (1.4 mmol/L) in water solution. The mixture was stirred for 12 hours at room temperature and 850 rpm. The synthesized ZIF-8 nanoparticles were collected by centrifugation at 11,000 rpm for 10 min and washed with deionized water three times. Enzyme encapsulated ZIF-8 (β-lact-ZIF8) were prepared by the same protocol, with 2-methylimidazole mixed with β-lactamase (2,5 mg/mL). The catalytic activity study was performed as follows; PEN solution (with varying concentrations of 0.1 mg/mL, 0.5 mg/mL and 1 mg/mL) was mixed with either 100 uL of free β-lactamase, 100 uL of β-lact-ZIF-8 or 20 mg or ZIF-8. Continual agitation was applied using orbital shaker at 200 rpm and room temperature. 1 mL of PEN solution was collected after 10, 20, 30, 60, 90, 120 min and monitored by the HPLC method.

Results

The catalytic study and performance of β-lactamase, β-lact-ZIF8 and ZIF-8 for the degradation of PEN was estimated in aqueous solution at room temperature. The results show excellent degradation properties of β-lact-ZIF8, compared to free β-lactamase. 90 % of PEN degraded under the catalytic reaction with β-lact-ZIF8 after only 10 min and was fully degraded after 120 min, while free β-lactamase and ZIF-8 degraded only 5 % and 66 % of PEN after 120 min, respectively (with equivalent concentration of the enzyme (2.5 mg/mL)).

Conclusions

The β-lactamase encapsulated MOFs shows excellent properties for the degradation of PEN, which was significantly improved when compared to the use of free enzyme. The research provides an important insight into the antibiotic biodegradation pathways for water remediation and the environment.

Keywords: β-lactamase, antibiotics, metal-organic frameworks, degradation, pollutant removal

Acknowledgement

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Mineral Waste Into Alkali-Activated Pavements

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The immense consumption of natural resources is putting an unprecedented strain on the planet, depleting finite reserves and causing considerable environmental damage. To mitigate these effects, the recycling of mineral waste has become essential. By recovering valuable minerals from waste products, we can reduce the demand for new resources, lower energy consumption and minimize the environmental footprint. This sustainable practice not only conserves vital resources, but also promotes a circular economy by ensuring that materials are reused and repurposed, extending their life cycle and reducing their overall environmental impact.

In the present work, we have developed a mix design for alkali-activated pavement slabs. Material quality, thickness, sufficient flexural (and compressive) strength, suitable surface finish (e.g. non-slip surface), durability (weather and abrasion resistance), environmental compatibility, etc. are important parameters to be

considered when developing new pavements. Different waste materials (e.g. bio-ashes, different slags, waste mineral wool) were used and many different mix designs were carried out to find the most suitable one. Not only the mechanical properties, but also the workability of the mixture, the water resistance and the leaching parameters were of great importance in deciding which mixture should be considered for further optimization and which should not. The mix design based on bio-ash, ladle slag and metakaolin alkali-activated with sodium silicate resulted in good mechanical properties. Environmental acceptability of reused mineral waste into new products show low concentrations of toxic elements, which were determined by a leaching test. The curing of the material is highly dependent on the selected precursors, which react with the further process of alkali activation and the curing process itself. In order to consume less energy, the curing process was carried out at room temperature and demolded after one day. Resistance to freeze-thaw in the presence of salt and abrasion resistance will be tested to ensure the quality and safety of paving block surfaces. In addition, the selected mixtures will be used for the preparation of the testing field at Termit d.d., which will provide information on the suitability of these products for further commercial use.

Keywords: pavement slabs, alkali activation, recycling, mineral waste, environmental acceptable

Acknowledgement

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High-Pressure Stirred Reactor System for High-Throughput Process Screening and Optimization

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The Parr 5000 system was acquired as part of the SRIP Krožno with co-investors Helios TBLUS and Steklarna Hrastnik. Six magnetically stirred 75 mL reactors enable chemical, catalytic and enzymatic processes at temperatures up to 300 °C, a pressure of 200 bar and under vigorous stirring up to 1000 rpm. Each reactor can be independently controlled in terms of parameters such as temperature, pressure and stirring speed, allowing a wide range of conditions to be studied in a single run. The system features advanced temperature control mechanisms, including heating jackets, which ensure precise and consistent temperature control. The reactors are designed to operate under high pressure and can be pressurized with gases such as hydrogen (fume hood with sensors) or oxygen, with safety features ensuring safe operation under high pressure. Efficient mixing of the reactants is ensured by magnetic stirring mechanisms, which are crucial for uniform reaction conditions and optimum reaction rates.

The system is typically integrated with sophisticated data acquisition and control systems, including software for real-time monitoring, data logging and control of all critical parameters, improving the precision and reproducibility of experiments. The reactors are made of materials that are compatible with a wide range of chemicals, such as stainless steel (T316) or Hastelloy, ensuring durability and reliability. Comprehensive safety features such as rupture discs and interlocks ensure safe operation under various reaction conditions.

The ability to run multiple reactions simultaneously increases throughput and reduces the time required for experimentation and optimization. In combination with advanced characterization techniques (XRD, XPS, TEM, TPD, etc.), first-principle DFT studies and microkinetic regression of experimentally obtained data, chemical process development is provided with an improved data basis for future developments (Lavrič et al., 2024).

Keywords: biomass utilization, reaction engineering, multiscale modeling, process optimization, stirred reactor system

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The 7th International Conference on Technologies & Business Models for Circular Economy (TBMCE) was organized by the Faculty of Chemistry and Chemical Engineering, University of Maribor in collaboration with the Strategic Research and Innovation Partnership - Networks for the Transition into Circular Economy (SRIP- Circular Economy), managed by the Chamber of Commerce and Industry of Štajerska. The conference was held in Portorož, Slovenia, at the Grand Hotel Bernardin from September 4th to September 6th, 2024. EIT RawMaterials RIS Hub Adria, SPIRIT Slovenia Business Development Agency and Pomurje Technology Park (as part of the GREENE 4.0 and CI-Hub projects) have joined us as co-organizers. TBMCE 2024 was devoted to presentations of circular economy concepts, technologies and methodologies that contribute to the shift of business entities and society as a whole to a more responsible, circular management of resources. The conference program included panel discussions, plenary and keynote sessions, oral and poster presentations on the following topics: Sustainable Energy, Biomass and Alternative Raw Materials, Circular Business Models, Secondary Raw Materials and Functional Materials, ICT in Circular Economy, Processes and Technologies. Panel discussions addressed following topics: Circular Economy Transition in South East Europe, The transition to carbon neutrality in energy intensive industry, Valorization of used and contaminated wood, Circular economy trends in construction, Critical raw materials and circular economy transition, Industrial Symbiosis and its opportunities for industry, AI and circular economy. The event was under the patronage of Ministry of the Economy, Tourism and Sport and Ministry of Cohesion and Regional Development.

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