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Sanja POTRČ Miloš BOGATAJ Zdravko KRAVANJA Zorka NOVAK PINTARIČ
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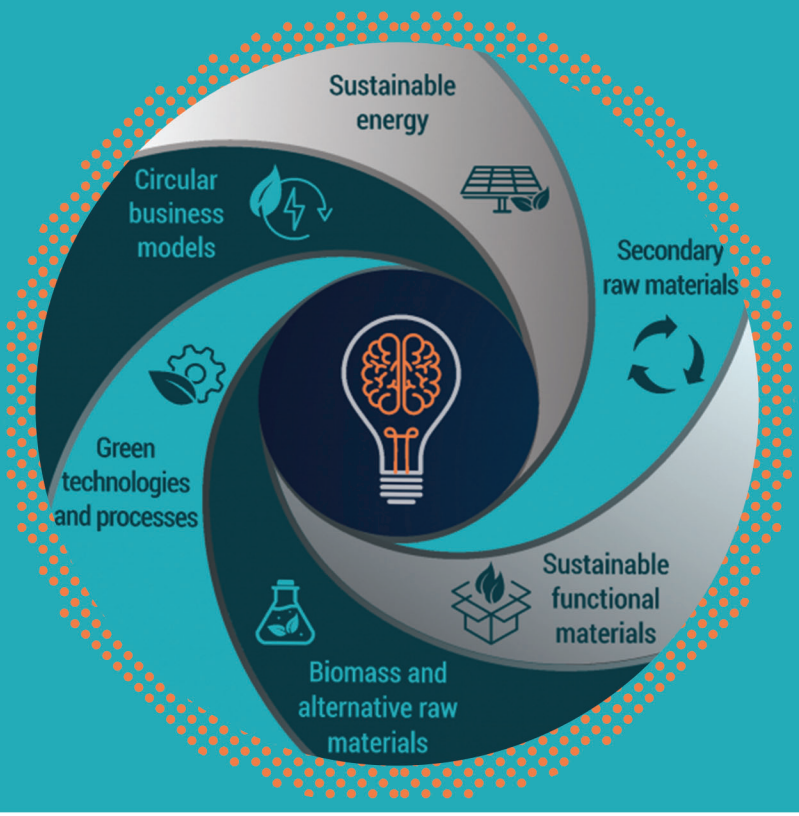

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Miloš Bogataj
Zdravko Kravanja
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6TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
BOOK OF ABSTRACTS
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Environmental and Economic Factors of Electric Vehicle Integration in Public Transport

URBAN ŽVAR BAŠKOVIČ, PATRICIJA CIRAR, ŽIGA ROSEC, DAVOR RAŠIĆ, JANEZ BLAŽ, ROK VIHAR, TINE SELJAK, TOMAŽ KATRAŠNIK

The presented study focuses on the introduction and utilization of various alternative electrified propulsion systems in Slovenian Public Passenger Transport (JPP) and Ljubljana Passenger Transport (LPP), with the objective of analyzing their potential impacts on reduction of CO_2 and pollutant emission as well as evaluating their economic feasibility. The study can be divided into two parts – first one being experimental campaign of on-road exhaust emission measurements of a EURO VI diesel bus and the second one being analysis of the data and evaluation of scenarios introducing electrified powertrains to JPP and LPP.

Within the first part of the study, a modern intercity diesel bus, part of the LPP fleet, was equipped with a GPS measurement device, an on-board diagnostics (OBD) logger, and engine-out emission measurement devices. Measurements of bus operation were conducted under real driving conditions on three regular LPP lines, representing a typical mixed city-intercity line, a hilly line, and a fast line that included highway section. The acquired results enabled the investigation of gaseous emissions

in various driving conditions for a diesel-powered bus, which is a representative of a typical intercity bus used in public transport in Slovenia.

In the second part of the study, results from the first part were used to evaluate potential of powertrain electrification to reduction of emissions of pollutants and CO_2 footprint. Since currently only diesel-powered buses are used in intercity transport in Slovenia, five distinct scenarios that suggest different proportions of the existing vehicle fleet to be replaced were evaluated. The initial two scenarios involve replacing 20% of the diesel buses with hydrogen fuel cell buses and battery electric buses. The subsequent two scenarios increase this replacement proportion to 80%, while the final scenario considers a complete fleet replacement with alternative electrified powertrains – 50% electric buses and 50% fuel cell buses. For all five scenarios, emissions of pollutants, CO_2 emissions during production and usage of energy vectors and economic aspect were evaluated for JPP and LPP separately.

The evaluation of pollutant emissions indicates that scenarios 3, 4, and 5 successfully align with the national objectives for reducing emissions of NO_x and THC based on the year 2005. Analyzing the CO_2 emissions in JPP, the study identifies the third scenario, which involves an 80% substitution of diesel buses with battery electric buses, as the most effective in terms of achieving the lowest emissions. In the case of LPP, however, the fifth scenario, consisting of an equal mix of 50% hydrogen fuel cell buses and 50% battery electric buses, emerges as the one with lowest CO_2 emissions. Considering emission of pollutants, CO_2 emissions and economic aspect, the third scenario proves to be a favorable option for both JPP and LPP since it strikes a balance between emissions reduction and economic feasibility, making it a promising choice for implementation.

The study's findings provide valuable insights into the potential of alternative electrified propulsion systems in Slovenian public passenger transport, considering both the environmental and economic aspects.

Keywords: Public passenger transport, buses, electrified powertrains, economic feasibility, environmental goals

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The authors would like to acknowledge the support received from the CRP V2-2134 project titled: »Priprava strokovnih podlag, zasnova baze podatkov in razvoj simulacijskega modela vozila za izračun energetskega in okoljskega odtisa za namen optimizacije izvajanja gospodarske javne službe javnega potniškega prometa«.

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Case Study of Digital and Circular Transformation Interaction in Foundries

LUKA KRAJNC, MARKO BOJINOVIĆ, GREGA KLANČNIK, ANDREJ RESNIK

The presented case study for combining digital and circular transformation is a digital solution for increasing the addition of circular material (DigitKroM). The digital solution strives for a vision of development and support of the Slovenian metallurgical/foundry and other manufacturing and processing industries as a creative, smart, technologically sovereign industry that promotes technological competitiveness, excellence and raises the competence of employees, enables the rise of innovation, and most importantly, places the digital solution in area of the green transition and is in line with the strategic development goals of the Republic of Slovenia and the European Union. DigitKroM takes part in the transformation of society through economic management of resources with the activities given below and strives for climate neutrality while intensively reducing the existing environmental footprint, reducing the use of energy-, emission- and cost-effective primary raw materials (BF pig iron, FeMo, FeSi, FeV) and their replacement with secondary material. This means also overall change in products production history. As a result, reducing dependence on strategic raw materials has a direct impact on reducing sensitivity to global uncertainty in the supply of raw materials and energy products, which are necessary for their development. With the DigiKroM product, we increase the effectiveness of the production of final products in the foundry and enable the replacement of raw materials with demanding secondary raw materials, as

an example of high-quality recycling in the technical capabilities of a given product with increased material efficiency through a circular economy for the reuse of products. The use of more demanding secondary material has a direct impact on the final product and additionally on the achieved more favorable own price and thus on the possibility of increasing the added value of the product, which is only feasible with adequate knowledge/research support for the placement of these raw materials on the existing technological path. With the presented case study, we will demonstrate the transition to a long-term system of more efficient use of more demanding "domestic" raw materials and other secondary raw materials of worn-out products with a short "life" cycle length, which enables a quick and repeatable return of material to the process of manufacturing new products, especially glassmaking tools. The pursuit of the origin of raw materials and the flow of mass and information-digital flows will take place with the DigitKroM product, as it is absolutely necessary to comprehensively manage the use of such materials and their use.

Keywords: circular economy, digitalization, technological optimisation, production process.

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Enzymatic Hydrolysis of Textile and Cardboard Waste as a Glucose Source for the Production of Limonene in *Escherichia coli*

ŽIGA ZEBEC, MOJCA POBERŽNIK, ALEKSANDRA LOBNIK

Cellulose containing textiles (cotton) and cardboard/carton waste represent a large reservoir of untapped organic carbon. These wastes have enormous potential for use as carbon feedstock in industrial biotechnological processes. Essentially, cotton/cardboard (CC) waste is pure cellulose (with some additives) in the form of polymerised glucose consisting of β-(1→4)-linked D-glucose subunits. One of the largest and most diverse classes of natural chemicals that can be produced from glucose are terpenes with a wide range of applications as flavours, fragrances, pharmaceuticals, biopesticides, and biofuels. Here we have investigated the bioconversion of CC waste into the exemplary terpene limonene as a proof of concept. Six different CC waste streams were enzymatically hydrolysed and used to produce limonene using the *Escherichia coli* (*E. coli*) microbial cell factory. The D-glucose content in the CC hydrolysate (glucose juice) was determined and then metabolised by *E. coli* via a manipulated heterogeneous biolipid synthesis pathway (the mevalonate pathway) to produce limonene. This study represents an important proof of concept for the production of terpenes from hydrolysed CC waste streams.

Keywords: cotton/cardboard (CC) waste; enzymatic hydrolysis; glucose juice; synthetic biol- ogy; limonene

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Waste Rubber Incorporated in the Alkali-Activated Metakaolin's Aluminosilicate Network Enhanced by Microwave Irradiation

BARBARA HORVAT, BRANKA MUŠIČ

Rubber represents a major challenge at the end of its life cycle due to its enormous quantities and recycling issues. Because rubber is rather elastic, its inclusion in various civil engineering products can provide many benefits, such as reducing stiffness, improving durability, dampening vibrations, and reducing road noise, while extending the usage life of the rubber by refurbishing and increasing the benefits to the users of the civil engineering product.

Therefore, the win-win solution is to incorporate coarsely ground waste rubber into alkali-activated material (AAM) that can be used as paving stones which would hinder the impact on the joints for users (when walking or running).

In the study, waste rubber from electric cables milled below 2 mm was used, while metakaolin was used as a precursor for AAM. Metakaolin was mixed with Na-silicate solution in a molar ratio that ensures the prevention of efflorescence and high mechanical strength [1,2].

AAM samples were prepared in two ways, i.e., (a) rubber being present only on the active surface or slightly below the active surface of the AAM, and (b) rubber being present throughout the volume of AAM. Samples were cured either solely at room conditions or immediately after moulding also with microwaves at 100 W or 1000 W for 1 min, to achieve better dissolution of the metakaolin or to physically foam the AAM into alkali-activated foam (AAF).

The encapsulation of rubber in ASN was evaluated by SEM, while the chemical influence on ASN was determined by EDXS, FTIR, and XRD.

Rubber got permanently incorporated into the aluminosilicate network (ASN) of AAM and AAF, while the 14-day-old mechanical strengths of unfoamed AAM still achieved sufficient values for pavements, especially when irradiated with microwaves with 100 W. From the results it is possible to conclude, that waste rubber has the potential to be refurbished in alkali-activated materials.

Keywords: waste rubber, alkali-activated metakaolin, encapsulation of organic in inorganic, material, microwave irradiation, mechanical properties

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References

Horvat, B.; Mušič, B.; Pavlin, M.; Ducman, V. Microwave Irradiation of Alkali-Activated Metakaolin Slurry.; September 2022.

Horvat, B.; Mušič, B.; Pavlin, M.; Ducman, V. Microwave Irradiation of Alkali-Activated Metakaolin Slurry. In Proceedings of the 5th International Conference on Technologies & Business Models for Circular Economy: Conference Proceedings; University of Maribor Press, January 30 2023; pp. 9–24.

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Progress of Urban Climate Planning in European Mediterranean Cities

KLAVDIJA RIŽNAR, FILOMENA PIETRAPERTOSA, MARTA OLAZABAL, SOFIA G. SIMOES, MONICA SALVIA, PARIS A. FOKAIDES, BYRON I. IOANNOU, VINCENT VIGUIE, NIKI-ARTEMIS SPYRIDAKI, SONIA DE GREGORIO HURTADO, DAVIDE GENELETTI, OLIVER HEIDRICH, LEA TARDIEU, EFREN FELIU, MARKO MATOSOVIĆ, MARIO V. BALZAN, ALEXANDROS FLAMOS, NATAŠA BELŠAK ŠEL, DIANA RECKIEN

Urban adaptation planning is widely seen as an instrument to reduce risks from climate impacts (Carter et al., 2015; Guyadeen et al., 2019). Local governments have a crucial role to play in the implementation of climate adaptation - related actions (Dale et al., 2020). Based on a Eurostat sample of 73 cities located in 51 regions across 9 Mediterranean Europe countries (France, Italy, Spain, Greece, Portugal, Croatia, Slovenia, Cyprus and Malta), the EURO-LCP initiative has been studying the status, quality, adequacy, progress and effectiveness of local climate planning (mitigation and adaptation) and disseminating its results. The main objective was to collect information and generate knowledge to improve the quality of local climate planning and promote the implementation of climate actions for wider urban resilience and sustainability in Europe. City sample selection, gathering of adaptation planning documents, questionnaire and content analysis, index construction and data analysis as methodological steps were used. Across the sample, 67 % of regions have adopted a plan, but only 30 % of the cities. European cities have improved in their abilities to plan for adaptation. These improvements may come about through processes of collective learning, knowledge transfer, capacity building, transnational

networks and other types of science-policy collaborations. However, urban climate change adaptation Plan Quality in European cities is increasing from 2005 to 2020, specifying adaptation goals improved most in recent years, adaptation plans are consistent to a degree between impacts of/ risks to specific hazards and adaptation goals and impacts of/ risks to industries and measures and most local governments are still not considering the needs of vulnerable people, nor involving them in policy formulation or monitoring whether adaptation measures reduce their vulnerability to climate threats (extreme temperatures and rainfall, followed by drought and water scarcity, as well as floods and landslides.)

Keywords: Climate adaptation, National adaptation plan, Local climate plans, Adaptation plan quality, Climate impacts

References

Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. Progress in Planning, 95, 1–66. https://doi.org/10.1016/j.progress.2013.08.001

Guyadeen, D., Thistlethwaite, J., & Henstra, D. (2019). Evaluating the quality of municipal climate change plans in Canada. Climatic Change, 152(1), 121–143. https://doi.org/10.1007/s10584-018-2312-1

Dale, A., Robinson, J., King, L., Burch, S., Newell, R., Shaw, A., & Jost, F. (2020). Meeting the climate change challenge: Local government climate action in British Columbia, Canada. Climate Policy, 20(7), 866–880. https://doi.org/10.1080/14693062.2019.1651244

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New Approaches to CAPEX and OPEX Evaluation in Case of Environmental and Circular Technologies Investment

ERIK MIHELIČ, DUŠAN KLINAR, KLAVDIJA RIŽNAR

We present a new view on the techno-economical assessment (TEA) of investments in environmental and circular technology processes, focusing on capital (CAPEX) and operational (OPEX) expenses. Traditional views on TEA results do not relevantly present the actual situation, especially in investment in environmental and material recycling technologies. Use of waste or side products as input material demand flexible and efficient technology capable of producing a product under different initial (input) conditions. The focus is not on implementing the economy of scale but on optimizing the process for given quantities and quality of inputs to minimize operating costs. Investment costs can be potentially higher while the investment can be partly subsidized by the State or financed from special funds. Flexibility of designed technology is essential as it allows lower operating costs and greater system flexibility regarding input material quality variation. Therefore, flexibility and technological performance become more important criteria than pure ROI and NPV results.

Two technological examples are presented as an illustration of the application of the new approach. The first relates to developing environmental technology, drying, and mono combustion of municipal sewage sludge. With this example, we want to illustrate the different alternatives for sludge drying, which require different investment and operating costs. In the case of sludge drying, two crucial factors were considered, namely drying time and thermal integration. Another example is related to the transition to a circular economy and deals with the issue of spent pot linings (SPL), a waste material from aluminium smelting process. The technology needs to be versatile enough to treat different granularities of cathode waste and efficiently extract hazardous substances at room temperature. Again, the focus is on reducing operating costs, emphasizing the flexibility and performance of the technology while keeping CAPEX optimal and keeping OPEX costs low.

Transporting hazardous waste incurs significant costs and risks, making economies of scale less meaningful. Therefore, the choice of technologies for dangerous waste treatment should favour low OPEX and potentially optimal CAPEX while emphasizing equipment quality and whole process automatization. These factors contribute to lower energy and material consumption, operation at lower temperatures, and overall higher efficiency. These insights could contribute to more efficient, scalable, and flexible technology development in the context of environmental problems remediation and the transition to the circular economy.

Keywords: CAPEX, OPEX, Circular Economy, Environmental Technologies, Sludge, SPL Cycle

References

Changotra, R., Rajput, H., Guin, J. P., Khader, S. A., & Dhir, A. (2020). Techno-economical evaluation of coupling ionizing radiation and biological treatment process for the remediation of real pharmaceutical wastewater. Journal of Cleaner Production, 242, 118544. https://doi.org/10.1016/J.JCLEPRO.2019.118544

Ghafourian, M., Nika, C. E., Mousavi, A., Mino, E., Al-Salehi, M., & Katsou, E. (2022). Economic impact assessment indicators of circular economy in a decentralised circular water system — Case of eco-touristic facility. Science of The Total Environment, 822, 153602. https://doi.org/10.1016/J.SCITOTENV.2022.153602

Girault, G., Petit, S., Rheault, J., Mercereau, D., Verzat, B. (2015). Use of the Life Cycle Assessment Methodology to Support Sustainable Aluminum Production and Technology Developments. In: Hyland, M. (eds) Light Metals 2015. Springer, Cham. https://doi.org/10.1007/978-3-319-48248-4_87

Medina-Martos, E., Istrate, I. R., Villamil, J. A., Gálvez-Martos, J. L., Dufour, J., & Mohedano, Á. F. (2020). Techno-economic and life cycle assessment of an integrated hydrothermal carbonization system for sewage sludge. Journal of Cleaner Production, 277, 122930. https://doi.org/10.1016/J.JCLEPRO.2020.122930

Pahunang, R. R., Buonerba, A., Senatore, V., Oliva, G., Ouda, M., Zarra, T., Muñoz, R., Puig, S., Ballesteros, F. C., Li, C. W., Hasan, S. W., Belgiorno, V., & Naddeo, V. (2021). Advances in technological control of greenhouse gas emissions from wastewater in the context of circular economy. Science of The Total Environment, 792, 148479. https://doi.org/10.1016/J.SCITOTENV.2021.148479

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Energy Management of Buildings with a Focus on Munucipalities

KAROLÍNA SMUTKOVÁ, JIŘÍ GREGOR, PETAR SABEV VARBANOV, PETR STEHLÍK

Given the climate situation (Adger et al., 2003; Akhmat et al., 2014) and the EU policy, it is necessary to take a conceptual approach to the energy optimization of municipalities as a whole. One of the sub-issues here is the optimisation of buildings. The reality in the Czech Republic is that municipalities, with a few exceptions, do not combine data on energy and water consumption with the actual technical condition of the buildings concerned, so they have no basis for decision-making and individual projects are often dealt with in an unconceptual and ad-hoc manner. This paper provides a summary of the datasets that municipalities should gather for energy management. The paper further discusses suggestions for the possibilities of handling such data, the establishment of indicators and the possibility of realistic implementation steps for the aforementioned issues.

Keywords: energy management, municipality, renewable energy, measurement and regulation in the energy sector, green deal

References

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. Progress in Development Studies, 3(3), 179–195. https://doi.org/10.1191/1464993403ps060oa

AKHMAT, Ghulam, Khalid ZAMAN, Tan SHUKUI a Faiza SAJJAD. Does energy consumption contribute to climate change? Evidence from major regions of the world. *Renewable and Sustainable Energy Reviews*. 2014, **36**, 123-134. ISSN 13640321. Dostupné z: doi:10.1016/j.rser.2014.04.044

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Bio-Based Resins for Coatings

NATAŠA ČUK, MARTIN OCEPEK, MIHA STEINBÜCHER, NEJC VIDMAR, JAKA LANGERHOLC, PETER VENTURINI

Polyesters are one of the most important classes of polymers for coatings. Besides synthetic monomers there are many monomers that originate from renewable resources available for their synthesis, including acids (succinic acid, sebacic acid, adipic acid, levulinic acid, gluconic acid, terephthalic acid, 2,5-furandicarboxylic acid, itaconic acid, lactic acid, 3-hydroxypropionic acid, etc.), and glycols (ethylene glycol, 1,3-propanediol, 1,4-butanediol, 1,5-pentanediol, isosorbide, xylitol, sorbitol, glycerol, etc.) (Nakajima et al., 2017, Ma et al., 2022, Lomelí-Rodríguez et al., 2018).

There are two main approaches when introducing a bio-based raw materials: a) conventional substance is substituted with bio-based alternative and b) so-called drop-in approach where fossil-fuel derived raw material is substituted with the chemically identical substance which is derived from biomass. In addition, the mass balance method of ISCC PLUS certification scheme can be used to determine the content of bio-based or recycled material.

In this research, fully bio-based and solvent-free polyester polyol for 2K polyurethane coatings and partially bio-based FDCA-derived resin for coil coatings were developed. In both cases, synthetic raw materials were replaced with bio-based alternatives and mass balance approach was used.

The results showed that the properties of bio-based resins complied with the requirements and were comparable to the properties of standard resin. For coatings prepared from bio-based resins the properties were comparable to the properties of coating prepared from standard resin.

Keywords: resins, bio-based, polyester polyol, polyurethane coating, coil coating

References

Lomelí-Rodríguez M., Corpas-Martínez J.R., Willis S., Mulholland R., Lopez-Sanchez J.A., 2018, Synthesis and characterization of renewable polyester coil coatings from biomass-derived isosorbide, FDCA, 1,5-pentanediol, succinic acid, and 1,3-propanediol, Polymers, 10, 600-618.

Ma Y., Xiao Y., Zhao Y., Bei Y., Hu L., Zhou Y., Jia P., 2022, Biomass based polyols and biomass based polyurethane materials as a route towards sustainability, Reactive and functional polymers, 175, 105285.

Nakajima H., Dijkstra P., Loos K., 2017, The recent developments in biobased polymers toward general and engineering applications: polymers that are upgraded from biodegradable polymers, analogous to petroleum-derived polymers and newly developed, Polymers, 9, 523-548.

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Development of a System for Harmonized Monitoring of Progress Toward a Circular Economy from Companies to Countries

ZORKA NOVAK PINTARIČ, JAN DROFENIK, TINKARA OŠLOVNIK, TINE SELJAK

A new European Action Plan for the Circular Economy (European Union, 2020) proposes to update the framework for monitoring the transition to a circular economy to be simple and based on European statistical databases. Monitoring systems for the circular economy are also being developed by several non-profit and profit organizations that offer tools for different levels: companies, cities, regions, countries. These tools differ from each other and do not fully match the indicators in the Eurostat database. The use of arbitrarily selected tools does not guarantee users that they can pursue the objectives of the European Union's circular economy.

This paper presents the development of an approach for harmonized monitoring of progress toward the circular economy at the corporate, regional, and country levels. The research is conducted within the Target Research Programmes (CRP) project in collaboration with the Ministry of Environment, Climate and Energy. The methodology used is based on the system for the micro level, i.e. companies (Baratsas et al., 2022), which is extended and adapted to municipalities and countries in this study.

The system defines the basic categories that are important for a circular economy: water, waste, energy, material consumption, emissions; other categories can be added as needed. In each category some basic physical quantities are selected, e.g., green energy consumption in the energy category. To maximize the integrability, input parameters are based on data and indicators that companies already monitor in their sustainability reports or that are monitored at the national level by the Statistical Office (SURS) or Eurostat. These data are converted into specific quantities (e.g., green energy consumption divided by total energy consumption) and converted into dimensionless numbers (indicators) expressed such that a value of 0 represents linear behaviour, while a value of 1 is circular. Using the selected weighted average of the indicators, sub-indices of circularity are calculated for each category and finally combined into an overall index of progress towards a circular economy.

The developed system is illustrated by the case study of a glass manufacturer, for which the data comes from publicly available sustainability reports, and for the country of Slovenia, where the data comes from the SURS database. A sensitivity analysis is performed to show the influence of each indicator on the sub-indices of the categories and on the overall circularity index. In this way, the areas that have the greatest impact on the circular economy are identified and a plan of priority actions to promote the transition from linear to circular economy can be developed.

Keywords: circular economy, monitoring, integrated system, companies, municipalities, countries

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References

Baratsas S. G., Pistikopoulos E. N., Avraamidou S. A., 2022, Quantitative and Holistic Circular Economy Assessment Framework at the Micro Level. Computers and Chemical Engineering, 160, 107697.

European Union, 2020, A new Circular Economy Action Plan, <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A98%3AFIN> accessed 15 July 2023.

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On the Role of Carbon Circularity for the Energy Transition

FRANÇOIS MARECHAL

Reaching net-zero energy system is not just a matter of efficiency and substitution of the fossil resources by renewable energy. The challenge concerns the energy management and the mitigation of the GWP gases emitted by the human activities. Reaching a net-zero emission system means therefore the integration of carbon sequestration and negative emissions technologies in the energy system. In my talk, Carbon Capture Usage and Sequestration will be investigated with a system integration perspective to design the future energy systems. We will in particular discuss the sources of GWP emissions in a renewable based system and in particular the role of the biomass as a source of biogenic carbon as well as renewable energy source. Combined with the CO_2 capture and sequestration techniques, we will discuss the role of process and energy system integration of biomass conversion, biorefineries and CCUS technologies. We will discuss the importance of carbon circularity as materials for chemical products and as energy carrier in the system. We will discuss how system integration of innovative technologies like fuel cells, electrolysis and separation technologies will need to be activated to reach the net-zero targets. Finally we will discuss the life cycle environmental impact metrics that can be used to measure the sustainability of the solutions proposed.

Keywords: energy transition, carbon neutrality, energy planning, carbon circularity, sustainability

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Influence of Polymeric Flame Retardants on the Flammability and Mechanical-Physical Properties of Polyurethane and Alkali-Activated Foams

BRANKA MUŠIČ, BARBARA HORVAT, NATAŠA KNEZ

Fire-safety requirements for construction industry materials are becoming ever stricter [1], not just for materials that are present on the market for a long time, but also for their future potential replacements

In the present research, two completely different building-industry materials were tested without and with the addition of halogen-free fire-retardant polymers (ammonium polyphosphates (APP) and 2,4,6-triamino-1,3,5-triazine (TATA)). One was the conventional flammable polyurethane foam (PUR) [1], which is used in various industries, including construction, e.g. for thermal insulation of windows and doors or fixing and sealing joinery, it can even be used as an insulating material on walls and roofs. And second was a non-flammable potential replacement for cements, mortars and ceramics, i.e. the alkali-activated material (AAM) based on metakaolin and Na-silicate solution, where alkali-activated slurry was cured in its early stage with microwaves at 100 W for 1 min [2,3], and such prepared can bear the high load.

APP and TATA were added to PUR and AAM in equal mass ratios, and compared to PUR and AAM without additives regarding the mechanical strengths measured at 14 days, explained with SEM-EDXS, MIP, FTIR and XRD analysis, and regarding their thermal and fire behaviour.

Keywords: polymeric flame retardants, polyurethane foam, alkali-activated foam, microwave foaming, flammability

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References

Mušič, B.; Knez, N.; Bernard, J. Flame Retardant Behaviour and Physical-Mechanical Properties of Polymer Synergistic Systems in Rigid Polyurethane Foams. *Polymers* 2022, 14, 4616, doi:10.3390/polym14214616.

Horvat, B.; Mušič, B.; Pavlin, M.; Ducman, V. Microwave Irradiation of Alkali-Activated Metakaolin Slurry.; September 2022.

Horvat, B.; Mušič, B.; Pavlin, M.; Ducman, V. Microwave Irradiation of Alkali-Activated Metakaolin Slurry. In Proceedings of the 5th International Conference on Technologies & Business Models for Circular Economy: Conference Proceedings; University of Maribor Press, January 30 2023; pp. 9–24.

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Waste Polyurethane Foams with/without Polymeric Flame Retardants Reused in Alkali-Activated Materials

BARBARA HORVAT, BRANKA MUŠIČ, NATAŠA KNEZ

Polyurethane foams (PUR) are used as thermal insulation in windows and doors, as insulating material for building walls, for fastening fence posts, as an electrical insulator, for soil reinforcement in geotechnical applications, but mostly in the furniture market etc. [1,2]. Its downside is that it is highly flammable [3], therefore different fire retardants are added [1]. Although additives that contain halogens are being replaced by environmentally acceptable materials like ammonium polyphosphates (APP) and 2,4,6-triamino-1,3,5-triazine (TATA) [1], PUR is still considered critical waste [2] (during incineration different hazardous chemicals are released, and if landfilled, PUR decomposes into environment-damaging substances). The win-win solution is to incorporate poorly-milled waste PUR into alkali-activated material (AAM) made from waste materials (containing amorphous Si and Al) and alkalis, i.e. PUR is safely and permanently incorporated in aluminosilicate network (ASN) of AAM, which becomes lightweight with changed insulating properties without the need for foaming with expensive, pure and health-hazardous chemicals, while mechanical strengths are still optimal.

Therefore, we milled PUR, PUR with APP (PUR-I) and PUR with TATA (PUR_II) [1] below 1 mm, added it into alkali-activate metakaolin with Na-silicate solution [4,5], in different mass ratios regarding alkali-activated slurry, treated it with microwaves at 100 W for 1 min to gain higher dissolution of ingredients due to rapid increase of temperature throughout the slurry, and gain higher compressive strength while shortening the curing time.

Mechanical strengths were measured at 14 days, while thermal and fire behaviours were tested on 28-day-old samples in comparison to PUR, PUR-I, and PUR-II. The incorporation of PUR with/without additives in ASN was evaluated by SEM-EDXS, and MIP, while chemical influence was determined by FTIR and XRD.

Keywords: waste polyurethane foam, polymeric flame retardants, alkali-activated material, thermal-fire behaviour, mechanical-physical properties

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References

Mušič, B.; Knez, N.; Bernard, J. Flame Retardant Behaviour and Physical-Mechanical Properties of Polymer Synergistic Systems in Rigid Polyurethane Foams. *Polymers* 2022, *14*, 4616, doi:10.3390/polym14214616.

Grolms, M. A New Method to Chemically Recycle Polyurethane Waste Available online: https://www.advancedsciencenews.com/solution-for-polyurethane-waste/ (accessed on 12 March 2023).

Günther, M.; Lorenzetti, A.; Schartel, B. Fire Phenomena of Rigid Polyurethane Foams. *Polymers* **2018**, *10*, 1166, doi:10.3390/polym10101166.

Horvat, B.; Mušič, B.; Pavlin, M.; Ducman, V. Microwave Irradiation of Alkali-Activated Metakaolin Slurry.; September 2022.

Horvat, B.; Mušič, B.; Pavlin, M.; Ducman, V. Microwave Irradiation of Alkali-Activated Metakaolin Slurry. In Proceedings of the 5th International Conference on Technologies & Business Models for Circular Economy: Conference Proceedings; University of Maribor Press, January 30 2023; pp. 9–24.

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Effect of Supercritical CO_2 on Activity and Conformational Changes in Selected Flour Enzymes

MILENA IVANOVIĆ, ŽELJKO KNEZ, DIETMAR HALTRICH, MAJA LEITGEB

Controlled enzyme activity in flour is of great importance for extending shelf life, and at the same time improving the quality of the final bakery product (Leitgeb et al., 2022). Green technologies using renewable and alternative sources, including supercritical carbon dioxide (sc-CO_2), are becoming a priority for researchers in a variety of fields, including enzyme activity control (Wu and Han, 2019). In this work, the effect of sc-CO_2 on the activity and conformational changes of the crude enzymes peroxidase (POD), lipase and alpha-amylase was evaluated at two different temperatures (35°C and 50°C) during the different exposure times (1h, 3h, and 6h). The residual activity of the enzymes was determined by a standard spectrophotometric methods, while circular dichroism (CD) and fluorescence spectra were evaluated to determine changes in their secondary and tertiary structure. In addition, the aggregation or dissociation of the enzyme molecules was examined based on the changes in particle size distribution and ζ potential.

The results of the activity assays showed a decrease in the activity of POD and lipase under optimal exposure conditions (6h and 50°C; and 1h and 50°C) by 22% and 16%, respectively. In contrast, no significant changes were observed in the activity of alpha-amylase, an enzyme desirable for the bakery industry, under the conditions studied. Consequently, analysis of the CD spectra of POD and lipase confirmed a

significant effect on the damage of the secondary structure (α-helix, β-sheet, and β-turn), while the secondary structure of alpha-amylase retained its original configuration. The fluorescence intensity of sc-CO_2 treated POD and lipase gradually decreased with increasing sc-CO_2 exposure time, without any λ_{em} shift, confirming the conformational changes at the active sites of the enzyme tertinarny structure. Finally, the observed changes in particle size distribution and ζ potential showed a significant effect of sc-CO_2 treatment on the aggregation and dissociation of the selected enzymes.

The results of this study confirm that sc-CO_2 technology can be effectively used as an environmentally friendly technology to control the activity of major flour enzymes by altering their secondary and tertiary structures.

Keywords: supercritical CO_2, enzyme activity, peroxidase, alpha amylase, lipase, CD spectroscopy, structure changes

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References

Leitgeb M., Knez Ž., Hojnik Podrepšek G., 2022, Enzyme Activity and Physiochemical Properties of Flour after Supercritical Carbon Dioxide Processing, Foods, 11, 1826.

Wu T., Han B., 2019, Supercritical Carbon Dioxide (CO_2) as Green Solvent, In: Mayers R.A (Ed), Encyclopedia of Sustainability Science and Technology Series, Springer, New York.

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Production of Micellar Structures from Medicinal Mushrooms

NIKA KUČUK, MATEJA PRIMOŽIČ, ŽELJKO KNEZ, MAJA LEITGEB

Introduction: The micellar structures of fungi, composed of cellulose, chitin, and various proteins, are one of the largest groups of organisms on Earth. The mycelium is a larger collection of intertwined hyphae and forms the vegetative part of the fungi. The advantages of micellar structures as biological materials are their adaptability to different growth conditions, biodegradability, and production costs. Due to their fibrous structure, they can be used for various biological purposes (Antinori et al., 2021; Khamrai et al., 2018), as well as in the fields of cosmetics, packaging, and construction (Majib et al., 2023; Manan et al., 2021).

Methods: The micellar structures were obtained from the medicinal mushrooms *Ganoderma lucidum* and *Pleurotus ostreatus*. The cultivation parameters, such as different liquid growth media, pH and cultivation time, were optimized to obtain the highest yield and water uptake capacity. The mycelial membranes were freeze-dried and then sterilized under UV light. Morphological characterization of the micellar membranes was studied using scanning electron microscopy (SEM). The structure of hyphae and their diameter were determined. In addition, Fourier-transform infrared spectroscopy (FTIR) analysis was used to determine the presence of a wide range of chemical functionalities on the surface of the micellar structures. Hydrodynamic characterization was also performed, such as the contact angle measurement to determine hydrophilicity/hydrophobicity and the kinetics of swelling.

Results: The results of our study show that micellar structures were successfully obtained from both selected medicinal mushrooms. Differences in the chemical nature of the micellar membranes were found using FTIR analysis when different liquid growth media were used. The maximum yield and the highest water uptake capacity of micellar structures with suitable properties were obtained by combining selected cultivation parameters. The micellar structures obtained from *P. ostreatus* showed better water absorption capacity (more than 600%) compared to the micellar structures of *G. lucidum* (up to 500%).

Conclusions: The synthesized micellar structures from medicinal mushrooms represent self-growing, fibrous, polymeric composites with suitable properties for potential applications in the packaging and construction industries. Further functionalization could also be promising for various biomedical applications.

Keywords: micellar structures, medicinal mushrooms, ganoderma lucidum, pleurotus ostreatus, characterization

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References

Antinori, M.E., Contardi, M., Suarato, G., Armirotti, A., Bertorelli, R., Mancini, G., Debellis, D., Athanassiou, A., 2021. Advanced mycelium materials as potential self-growing biomedical scaffolds. Scientific Reports. 11, 12630.

Khamrai, M., Banerjee, S.L., Kundu, P.P., 2018. A sustainable production method of mycelium biomass using an isolated fungal strain Phanerochaete chrysosporium (accession no: KY593186): Its exploitation in wound healing patch formation. Biocatalysis and Agricultural Biotechnology. 16, 548–557.

Majib, N.M., Sam, S.T., Yaacob, N.D., Rohaizad, N.M., Tan, W.K., 2023. Characterization of Fungal Foams from Edible Mushrooms Using Different Agricultural Wastes as Substrates for Packaging Material. Polymers 15, 873.

Manan, S., Ullah, M.W., Ul-Islam, M., Atta, O.M., Yang, G., 2021. Synthesis and applications of fungal mycelium-based advanced functional materials. Journal of Bioresources and Bioproducts. 6, 1–10.

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Simulation Assisted Development of SOC Systems

NEŽKA BRUNEC, ALEŠ CVIKL, IVO PRAH

Solid Oxide Fuel Cell and Electrolyzer (SOxC) represent one of the key technologies for the green hydrogen production (C. Y. Chan et al., 2023) referred to as one of the main energy carriers in the future energy industry (M. León et al., 2023) in order to achieve the goal of a carbon neutral EU by 2050 and meet the climate targets of the Paris Agreement (S. Potrč et al., 2021). Therefore, investments into research, development and industrialization of these technologies are getting momentum on the market, which is clearly reflected in growing of AVL's business with several running projects.

During complete development process of the SOxC systems, simulation tools are more and more important to reduce the number of prototypes, time, and costs while at the same time targeting better quality of the end product. For efficient simulation assisted development process, models have to consider all relevant thermodynamic and electro-chemical phenomena and additionally feature a short turnaround time (shorter than the real time). Likewise, mirroring the real SOxC system, the simulation model centres around the stack as its core component, including all other relevant balance of plant components. The electro-chemical stack model implementation in multidisciplinary system simulation tool AVL CRUISE™ M was based on (Kravos et al., 2022) and validated based on available data (P. Kazempoor, 2014), (L. Barelli et al., 2017) and other sources. In the presentation, the validation of the stack system will be shown together with the application of the model through entire

development process, starting with concept phase, where system layout and component sizing is in the focus. When system hardware architecture is defined, models are re-used for the purpose of control functions development and controller calibration for which some of the use cases will be presented.

At the end, further outlook and road map for the SOxC system simulation will be presented.

Keywords: solid oxide cell, fuel cell, electrolyzer,solid oxide stack, balance of plant, system, simulation, CRUISE™ M

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References

Andraž Kravos, Tomaž Katrašnik, 2022, Closed-Form Formulation of the Thermodynamically Consistent Electrochemical Model Considering Electrochemical Co-Oxidation of CO and H_2 for Simulating Solid Oxide Fuel Cells, Catalysts 2022, 12(1), 56, <https://doi.org/10.3390/catal12010056>

Chan, C.Y.; Rosner, F.; Samuelsen, S. Techno-Economic Analysis of Solid Oxide Fuel Cell-Gas Turbine Hybrid Systems for Stationary Power Applications Using Renewable Hydrogen. Energies 2023, 16, 4955. <https://doi.org/10.3390/en16134955>

L. Barelli, Gianni Bidini, Giovanni Cinti, Andrea Ottaviano, 2017, Study of SOFC-SOE transition on a RSOFC stack, International Journal of Hydrogen Energy, 42(41), <https://doi.org/10.1016/j.ijhydene.2017.08.159>

León, M.; Silva, J.; Ortíz-Soto, R.; Carrasco, S. A Techno-Economic Study for Off-Grid Green Hydrogen Production Plants: The Case of Chile. Energies 2023, 16, 5327. <https://doi.org/10.3390/en16145327>

P. Kazempoor, R.J. Braun, Model validation and performance analysis of regenerative solid oxide cells for energy storage applications: Reversible operation, Volume 39, Issue 11, 4 April 2014, Pages 5955-5971, <https://doi.org/10.1016/j.ijhydene.2014.01.186>

S. Potrč, L. Čuček, M. Martin, Z. Kravanja. Sustainable renewable energy supply networks optimization – The gradual transition to a renewable energy system within the European Union by 2050. Renewable and Sustainable Energy Reviews, 146 (2021) 111186. <https://doi.org/10.1016/j.rser.2021.111186>

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6TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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Optimizing Performance and Cost-Effectiveness of Different Rankine Cycle Configurations

MONIKA DOKL, ZDRAVKO KRAVANJA, LIDIJA ČUČEK

In last decades energy consumption significantly increased, leading to environmental problems such as pollution, resource depletion, and global warming. Achieving the long-term strategic goal of carbon neutrality requires a multi-faceted approach that includes increasing energy efficiency, broader use of renewable energy sources, and comprehensive integration of electricity into energy grids. Rankine cycle systems are characterized by high flexibility and compatibility with heat sources, facilitating distributed power generation and effective use of renewable energy sources. In addition to the characteristics of the heat source and the choice of working fluid, the configuration and architecture also affect the performance of a Rankine-based power system.

In addressing the trade-offs between thermodynamic performance and economic viability, various designs are evaluated to determine the optimal operating conditions in terms of highest energy efficiency and lowest system capital and operating costs. The integration of waste heat and renewable energy sources such as biomass, solar energy, and geothermal energy is based on a case study, where heat sources are available at high-, medium- and low-temperature levels. The process synthesis is modeled as a flowsheet structure forming a nonlinear programming model that considers the operating conditions as variables to be optimized. The optimal

configuration for the selected case study is determined, and the performance and feasibility of the systems are discussed.

Keywords: renewable energy, waste heat, Rankine cycle system, energy efficiency, economic optimization, system design

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Effect of Polyolefins Quality on Degradation in Supercritical Water

MIHAEL IRGOLIČ, MAJA ČOLNIK, PETRA KOTNIK, LIDIJA ČUČEK, MOJCA ŠKERGET

Plastic pollution has become an increasingly alarming global problem, with polyolefins, a type of plastic commonly used for packaging and other applications, playing a major part. These polyolefins, including polyethylene (PE) and polypropylene (PP), are known for their durability and degradability, remaining in the environment for hundreds of years (Čolnik et al. 2022). The accumulation of plastic waste poses a serious threat to ecosystems, wildlife and human health. Recycling plastics has long been considered a possible solution to alleviate the plastic waste crisis. However, traditional recycling methods face many challenges. Mechanical recycling methods, which are the most commonly used, are limited by the deterioration in quality of plastics with repeated processing, resulting in lower value and usability of the recycled material (Cecon et al. 2021). Supercritical water hydrolysis, an innovative and environmentally friendly technology, has emerged as a promising approach to overcome the challenges of recycling polyolefins. Water in a supercritical state can efficiently dissolve a wide range of organic compounds, including polyolefins, without the need for additional solvents. The use of supercritical water for plastics recycling offers several advantages. First, it enables the complete depolymerisation of polyolefins by breaking them down into their individual monomers or shorter chain hydrocarbons. These monomers can then be used to produce new plastics or other valuable chemicals. Secondly, the process is environmentally friendly as it avoids the use of hazardous solvents or the generation

of harmful byproducts (Queiroz et al. 2020). This innovative and environmentally friendly technology has the potential to change the way we deal with plastic pollution, promote a circular economy and pave the way to a more sustainable future.

A comparison of the degradation of virgin and recycled polyolefins (PE and PP) by a hydrothermal batch process was carried out. The degradation was carried out at 450 °C and reaction times from 15 min to 240 min. The degradation products were obtained in three phases: oil, solid and gas. The maximum oil yield was obtained at a reaction time of 30 min for PP degradation and at a reaction time of 60 min for PE degradation. The maximum oil yield was 0.7 % (PE) to 5.4 % (PP) higher in the case of the virgin material than in the case of the recycled material. The most obvious difference between the virgin and the recycled material was in the solid residue, the yield of which was much higher in the case of the recycled material. The solid residue yield after 240 minutes was 1.2 % for the virgin PE degradation and 8.7 % for the recycled PE degradation. An even greater difference occurred for PP degradation, where the solid residue yield after 240 minutes was 0.9 % for virgin PP and 11.1 % for recycled PP.

The results of the study show that the quality of the material influences the decomposition results and is an important factor in the design of the hydrothermal process.

Keywords: polyolefins degradation, supercritical water, recycled plastic, polypropylene, polyethylene, chemical recycling

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References

Cecon V.S., Da Silva P.F., Curtzwiler G.W., Vorst K..L., 2021, The challenges in recycling post-consumer polyolefins for food contact applications: A review, *Resources, Conservation and Recycling,* 167, 105422.

Čolnik M., Kotnik P., Knez Ž., Škerget M., 2022, Chemical Recycling of Polyolefins Waste Materials Using Supercritical Water, *Polymers,* 14, 4415.

Queiroz A., Pedroso G.B., Kuriyama S.N., Fidalgo-Neto A.A., 2020, Subcritical and supercritical water for chemical recycling of plastic waste, *Current Opinion in Green and Sustainable Chemistry,* 25, 100364.

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Isolation of Keratin from Wool and Feathers with Alkaline Hydrolysis

KLEMEN GRADIŠNIK, MAJA ČOLNIK, MOJCA POBERŽNIK,
ALEKSANDRA LOBNIK, MOJCA ŠKERGET

Keratin is a fibrillar structural protein found in various body tissues of animals and humans (wool, feathers, hair, nails, beaks, scales) (Sharma et al., 2016). In recent years, keratin has attracted great interest in biomedicine (wound healing, antioxidant activity) (Feroz et al., 2020), pharmaceuticals (tissue engineering, drug delivery), and cosmetics (for smoothing and hydrating the damaged scalp and improving skin elasticity) (Sharma et al., 2016). Some of the keratin sources are available virtually for free, as many are waste biomass or residues from various industries. According to statistics from the US Food and Agriculture Organisation (FAO), global meat production has increased by 47 % since 2000, reaching 342 million tonnes in 2018. This indicates that a very large amount of biomass (keratin-rich waste) has also been produced. Therefore, the use of waste biomass to produce keratin represents a great potential. By beneficially using industrial wastes (which are currently usually incinerated or landfilled) to obtain high-value products, the use of waste biomass could reduce environmental impact and take a step toward sustainable practises. (Senthilkumar et al., 2022).

In this study, the isolation of keratin from waste sheep wool and poultry feathers was performed by alkaline hydrolysis. An aqueous NaOH solution at different concentrations (30-50 mg/mL) was used as the alkaline medium. The experiments were performed at different reaction times (1-3 h) and temperatures (50-80 °C). The

effects of the reaction conditions on the yield of the isolation products, the molecular mass of the isolates, and other product characteristics were studied.

The reaction product after alkaline hydrolysis was a clear, orange liquid. Some of the undegraded fibres of the starting material were still present in the post-reaction mixture, especially at low temperatures (50 °C) and low NaOH concentrations (30 mg/mL). The yield of isolates was quite high, ranging from 41.61% to 66.39 % for wool and from 38.98 % to 55.19 % for feathers, respectively. The highest yield of isolates from wool (66.39 %) was achieved at 50 °C, 3 h and 40 mg/ml, while the highest yield of isolates from feathers (55.19 %) was obtained at 50 °C, 2 h, and 50 mg/ml. The molecular masses of the isolated products were determined by SDS-PAGE electrophoresis. In most cases, the molecular masses were homogeneously distributed throughout the band and ranged from 4.6 to 315 kDa, but the predominant molecular mass of keratins ranged from 8 to 40 kDa. It was found that higher temperature (80 °C) and higher NaOH concentration (50 mg/mL) decreased the molecular mass of the products in the isolates. All isolates from wool and feathers showed relatively low antioxidant activity (about 20 %) and negative zeta potential. Particle size, conductivity measurements, and FTIR analyses of the isolates were also performed.

The results of this study show that wool and feathers present an excellent source of keratin isolates and that alkaline hydrolysis of waste biomass is a possible way to contribute to a cleaner environment and a circular economy.

Keywords: keratin, waste biomass, hydrolysis, wool, feathers, proteins

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References

Senthilkumar N., Chowdhury S., Sanpui P., 2023, Extraction of keratin from keratinous wastes: current status and future directions, Journal of Material Cycles and Waste Management, 25, 1-16.

Feroz S., Muhammad N., Ratnayake J., Dias G., 2020, Keratin - Based materials for biomedical applications, Bioactive Materials, 5, 496-509,

Sharma S., Gupta A., 2016, Sustainable Management of Keratin Waste Biomass: Applications and Future Perspectives, Brazilian Archives of Biology and Technology, 59, 1-16.

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Thermogravimetric Analysis of Pyrolysis of Hydrochar from Industrial Waste

ALEKSANDRA PETROVIČ, SABINA VOHL, IRENA BAN,
TJAŠA CENČIČ PREDIKAKA, LIDIJA ČUČEK

Increasing energy demand and concerns related to the use of fossil fuels have led to increased production of biofuels from renewable biomass. Processes such as anaerobic digestion, pyrolysis and torrefaction have been extensively studied for this purpose, while hydrothermal carbonization (HTC), which allows treatment of wet biomass at relatively low temperatures (up to 350°C) and is therefore more economically acceptable, has been less explored (Alshareef et al., 2021).

The hemp industry, which has grown rapidly in recent decades, generates various types of organic waste and byproducts that can be used to produce biofuels and other valuable products. Sesame, olive, sunflower, castor and some other oil press cakes have been successfully subjected to pyrolysis and hydrothermal carbonization (Rajpoot et al., 2022). Hemp seed oil cake has rarely been studied for biofuel production and is still mostly used as animal feed, although it is suitable for various applications, such as biochar production, supercapacitors, protein isolation, or extraction of valuable chemicals.

Several studies have addressed the kinetics of biomass pyrolysis, and various kinetic models, from differential to integral iso-conversional models, have been applied to describe the kinetics and determine the kinetic parameters (Rasam et al., 2020). Fewer studies have been devoted to the pyrolysis kinetics of hydriochars obtained by HTC treatment. The kinetics of pyrolysis of hemp oil cake and its hydrochar have not been studied in detail.

In this study, thermogravimetric analysis of pyrolysis of hydrochar obtained from hemp oil cake by hydrothermal carbonization was performed. The measurements were carried out in nitrogen atmosphere in the temperature range of 25-900 °C. Based on the thermogravimetric analysis data, the kinetic analysis of pyrolysis of hemp oil cake and hydrochar obtained from it was carried out using the Flynn-Wall-Ozawa (FWO) and Kissinger-Akahira-Sunose (KAS) iso-conversional kinetic models. The kinetic parameters such as the activation energy and the pre-exponential factor were calculated. The effects of HTC treatment on fuel properties and changes in pyrolysis kinetics were evaluated and compared with raw biomass.

Keywords: hydrothermal carbonization, hydrochar, oil cake, thermogravimetric analysis, kinetic analysis

References

Alshareef S.A., Otero M., Alanazi H.S., Siddiqui M.R., Khan M.A. and Alothman Z.A., 2021, Upcycling olive oil cake through wet torrefaction to produce hydrochar for water decontamination, Chemical Engineering Research and Design, 170, 13-22.

Rajpoot L., Tagade A., Deshpande G., Verma K., Geed S.R., Patle D.S. and Sawarkar A.N., 2022, An overview of pyrolysis of de-oiled cakes for the production of biochar, bio-oil, and pyro-gas: Current status, challenges, and future perspective, Bioresour. Technol. Rep., 19, 101205.

Rasam S., Moshfegh Haghighi A., Azizi K., Soria-Verdugo A. and Keshavarz Moraveji M., 2020, Thermal behavior, thermodynamics and kinetics of co-pyrolysis of binary and ternary mixtures of biomass through thermogravimetric analysis, Fuel, 280, 118665.

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Reducing Environmental Impacts Using an Innovative System to Exploit Excess Heat from Cogeneration Gas Engines

JAN PUHAR, DANIJELA URBANCL, DAMJAN KRAJNC,
ANNAMARIA VUJANOVIĆ, DARKO GORIČANEC

With growing demands for decreased emissions of greenhouse gases (GHGs) and the integration of renewable energy sources, including in the public building sector and district heating systems, there is a need for innovative technical solutions. It is evident that enhancing energy efficiency is crucial throughout the entire energy supply chain, from production to final consumption. The study introduces a new system that enables utilization of low-temperature surplus heat from gas engines powered by gas or liquid fuel for district heating, building heating, or industrial purposes (Goričanec & Urbancl, 2021). The system facilitates an enhancement in the primary fuel efficiency of gas engines used in combined heat and power (CHP) systems by harnessing low-temperature excess heat from exhaust gases and the cooling system, which are typically released into the environment. The typical configuration of district heating hot water systems involves the transportation of heated water at elevated temperatures to the heat consumer through the supply line. Subsequently, the cooled water is returned to the CHP gas engine. Through the utilization of innovative heat pumps in series, the proposed system effectively exploits the low-temperature waste heat as a heat source. Consequently, a larger

amount of usable heat can be generated while maintaining the same level of primary fuel consumption for heating purposes, thereby maximizing the fuel efficiency of the CHP gas engine and reducing CO_2 emissions. An assessment of the system's environmental impact is conducted through a Life Cycle Assessment (LCA), comparing two alternative systems: the conventional CHP gas engine process and the CHP gas engine process with interconnected heat pumps utilizing surplus heat. The assessment demonstrates substantial environmental advantages of this innovative technical solution, attributable to its enhanced energy efficiency and reduced CO_2 emissions.

Keywords: CHP gas engine, district water heating, heat pump, environmental impacts, Life Cycle Assessment

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References

Goričanec, D., Urbancl, D., 2021, Exploitation of Excess Low-Temperature Heat Sources from Cogeneration Gas Engines. In: *Energy Efficiency*, IntechOpen.

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Innovative Bio-Based Screen Printing Inks for Glass Bottles Decoration

LIZA MARIJA STRNAD, ANA VARLEC, TILEN SEVER, NATALIJA VIRANT, IVAN JERMAN, ANA DRINČIĆ, NIGEL VAN DE VELDE

In recent years, there has been growing interest in developing sustainable alternatives for printing in general, aiming to minimize the environmental impact associated with conventional materials and processes. Stricter regulations on the use of hazardous substances and demand for healthier and safer workplaces as well as demand for lowering CO_2 footprint are driving forces for such projects. In Steklarna Hrastnik we have identified a need for more environmentally friendly inks for glass bottles decoration. This work presents results of utilizing bio-based substitutes in screen printing ink formulations for glass decoration and its contribution to the advancement of circular economy principles.

The meaning of the word "bio" in “bio-polymer” in the context of inks can refer to different things: i) the monomers or polymers have been derived from renewable sources, ii) the material is biodegradable, or iii) the material is produced by biological processes (Albertsson, Hakkarainen, 2017). There is a limited number of studies exploring the use of formulations based on renewable materials (almost exclusively made from vegetable oils (Robert, 2015)) for screen printing, especially for the UV-curing inks (Brunner, Tafelmeier, 2010). Furthermore, the research of the said topic on glass substrate is even more scarce (Robert, 2015). The aim of our work was to replace part of fossil fuel carbon in the acrylic base ink with carbon from renewable sources.

Experimental studies have been conducted to evaluate the performance of different bio-based formulations. Studies were done using itaconic acid (ITA) as bio-based monomer, as it obtained by fermentation of carbohydrates. ITA is soluble only in ethanol or water therefore useless for application in solvent free acrylic systems. Incorporation of ITA in such system is possible by i) ball milling (dispersion of ITA without covalent interaction) or by ii) usage of green solvents. Different formulations were prepared and tested considering the above restrictions. The research for optimal solvent followed. Rheological parameters were adjusted, and pigment was incorporated. Distribution of ITA and pigments in the printed layers were analysed using Raman spectroscopy, profilometry and SEM analysis. Adhesion properties, printability, and durability have been key focus areas. After printing on laboratory scale, we have performed also testing on industrial scale. The results obtained from these experiments have provided valuable insights into the feasibility and potential challenges associated with implementing bio-based substitutes in screen printing inks for glass substrate.

In conclusion, this research demonstrates the viability of bio-based substituted inks for screen printing on glass substrates, offering an innovative approach towards the development of sustainable solutions for printing on the glass. It is the contribution to the ongoing efforts to advance circular economy principles and promote sustainable technologies in the glass decoration industry.

Keywords: bio-based inks, itaconic acid, industrial screen printing, printing on glass, substrate, circular economy, sustainability, renewable resources

References

Albertsson A.-C., Hakkarainen M., 2017, Designed to degrade, Science, 358, 872–874, [doi.org/10.1126/science.aap8115].

Brunner A., Tafelmeier E., UV or EB Curing Screen Printing Inks Containing a High Amount of Renewable/Sustainable Material. Patent No. PCT/EP2009/059920, 04.02.2010.

Robert T., 2015, "Green ink in all colors"—Printing ink from renewable resources, Progress in Organic Coatings, 78, 287-292.

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Characterization and Mechanical Properties of Sintered Clay Minerals

SARA TOMINC, VILMA DUCMAN, JAKOB KÖNIG, SREČO ŠKAPIN

The need to reduce energy consumption and the carbon footprint generated by the firing of various materials has stimulated research into the development of sintering, which is carried out at lower temperatures, ideally not exceeding 300 °C (Grasso et al., 2020). The so-called cold sintering process (CSP) is a process in which the inorganic powder is compacted in the presence of a transient liquid phase with a phase fraction usually between 1 and 10 percent by volume (Maria et al., 2017).

To evaluate the applicability of CSP for clays, our studies were conducted on representative clay minerals kaolinite (high and low defect) and illite. Kaolinite and illite are widespread clay minerals that occur naturally and are used for various applications. Kaolinite is of particular interest because it undergoes dehydroxylation to an amorphous state; metakaolin is formed, which is stable over a wide range of temperatures. The natural clay material used to make bricks was also used for research.

The selected clay minerals were first characterized (XRD, XRF, SEM analysis, PSD, BET, TG/DTA/DSC-MS) and then conventionally sintered at 1100 and 1300 °C for 2 hours to compare their mechanical properties with the samples prepared using CSP. The obtained mechanical and microstructural properties of the conventionally sintered pellets served as reference properties for evaluating the performance of the used CSP method.

Keywords: conventional sintering, cold sintering, clay minerals, characterization, mechanical properties

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References

Grasso S., Biesuz M., Zoli L., Taveri G., Duff A.I., Ke D., Jiang A., Reece M.J., 2020, A review of cold sintering processes, Advances in Applied Ceramics, 119:3, 115-143.

Maria J.P, Kang X, Floyd R.D, 2017, Dickley E.C., Guo H., Guo J., Baker A., Funihashi S., Randall C.A., 2017, Cold sintering: Current status and prospects, Journal of Materials Research, 32:17, 3205–3218.

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Advanced Solutions to Mitigate Plastic River Pollution: An Integrated Approach to Maintain the Health of European Waters

ANNAMARIA VUJANOVIĆ, JAN PUHAR

Restoring the health of a single connected European system of oceans, seas, coastal and inland waters is essential for the European Union to achieve its Green Deal goals and is the ambition of the Horizon Europe Mission to restore oceans and waters by 2030. This ambition is threatened by the fact that there are currently around 150 million tonnes of potentially harmful plastic, an amount which is expected to increase by 10% annually. Plastic and microplastic pollution of the oceans comes from a variety of sources, one of which is the pollution of rivers that carry litter and plastic into the sea. Therefore, it is important to develop solutions that prevent further pollution of rivers, not only for cleaner oceans, but also for the well-being of ecosystems and the preservation of biodiversity in freshwater. In order to achieve this, a significant reduction in plastic waste emissions is necessary, which can only be achieved through immediate and concrete measures, in which technological intervention plays an essential role. The work shows an integrated way to deal with plastic waste in rivers with measures along the entire plastic chain, which is realized with combinations of different technologies or solutions. The approach includes a total of 20 technologies and actions that combine the concepts of identification or detection of waste in water bodies, collection or waste disposal, and

preventing the entry of waste through measures to implement circular economic models.

Keywords: plastic pollution, microplastic, emission reduction, holistic approach, technological solutions

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Review of the Techno-Economic Assessment of Plastic Value Chains

XUEXIU JIA, CHUN YAN SI, DAMJAN KRAJNC, YEE VAN FAN, MONIKA DOKL, SANJA POTRČ, PETAR VARBANOV, LIDIJA ČUČEK, ZDRAVKO KRAVANJA

Minimizing plastic waste and its footprint is extremely important, as large quantities of plastic waste end up in landfills or are insufficiently addressed by the linear economy. Recent statistics revealed that more than 4,815 kg per capita of total waste was generated in the EU-27 in 2020 with a recycling rate of 58 % (Eurostat, 2021). Of the total waste, 43 kg per capita amounted to plastic waste in 2020 (Eurostat, 2023a). More than 80 % of the plastic waste corresponds to plastic packaging waste (Eurostat, 2023b), for which recycling rate was 37.6 % in 2020 (Eurostat, 2023c). There is still a great potential to enable plastic waste to re-enter the value chain. Investigating the techno-economic performance or the life cycle cost of plastic production and reuse can facilitate this goal. This study provides a literature review of the techno-economic analysis covering the whole life cycle of plastic products, while focusing mainly on the production and reuse/recycling phases. First, an introductive summary presents the commonly used methods and frameworks for the techno-economic assessment (TEA) and Life Cycle Costing (LCC) (Lorenzo, 2021), followed by the review and discussions of the studies that applied TEA and/or LCC to plastic production and/or recycling. It is found that the LCC values of plastic production and/or recycling based on existing studies vary significantly due to the differences in applied methods, system boundaries and analysed processes in these studies. Based on the literature review, potential research directions are

suggested, including 1) the Development of a unified and systematic methodology/framework for the TEA or LCC assessment of plastic production/reuse; 2) Integration of the TEA/LCC with environmental cost to enable the possibility of promoting sustainable use of plastic from a circular economic perspective; and 3) TEA or LCC implementation of the most commonly practised plastic reuse/recycle routes.

Keywords: plastic, value chain, techno-economical assessment, life cycle costing; plastic loop

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References

Eurostat, 2021. Data Browser, Circular economy indicators. <https://ec.europa.eu/eurostat/databrowser/view/CEI_PC034/default/table?lang=en&category=cei.cei_pc>

Eurostat, 2023a. Data Browser, Generation of waste by waste category, hazardousness and NACE Rev. 2 activity. <https://ec.europa.eu/eurostat/databrowser/view/ENV_WASGEN__custom_7024358/default/table?lang=en>

Eurostat, 2023b. Data Browser, Generation of plastic packaging waste per capita. <https://ec.europa.eu/eurostat/databrowser/view/CEI_PC050/default/table?lang=en&category=cei.cei_pc>

Eurostat, 2023c. Data Browser, Recycling rate of packaging waste by type of packaging. <https://ec.europa.eu/eurostat/databrowser/view/CEI_WM020/default/table?lang=en&category=cei.cei_wm>

Lorenzo Giacomella. Techno-Economic Assessment (TEA) and Life Cycle Costing Analysis (LCCA): discussing methodological steps and integrability. Insights into Regional Development, 2021, 3 (2), 176 - 197.

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6TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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Design and Manufacturing of Sustainable Industrial Packaging from Alternative Lignocellulosic Biomass

DAVID RAVNJAK, GREGOR ČEPON, ALEŠ MIHELIČ, TINA FRANGEŽ, JAWAD ELOMARI

Due to high demand and increasing prices of wood-based cellulose, alternative sources of lignocellulosic biomass are gaining on their importance. One of such sources are invasive alien plants (IAP) that must be constantly removed from the environment in order to protect the natural biodiversity. Currently this plant material is being discarded (burned or composted) in spite the fact that it contains significant amount of cellulose which can be converted to useful products. One of such potential products is the packaging for large home appliances, where currently expanded polystyrene (EPS) is used. By exchanging EPS with cellulose-based (from IAP biomass) packaging, the circular nature of the packaging will be improved while using the raw material from alternative, not wood-based source. Within the LEAP project the potential of IAP biomass for conversion to cellulose and its use for production of foam formed packaging materials for packing large home appliances is being studied. Based on the material properties of cellulose from IAP a computer model for designing the optimal packaging construction will be developed. In the first stage of the project various IAP have been evaluated in terms of their potential use for cellulose production, cellulose quality and key mechanical parameters for

production of foam formed packaging. Test specimens of foam formed cellulose based material have been produced and their mechanical properties have been evaluated. The data gathered is being used in computer assisted design and construction of packaging for large home appliances. A preliminary LCA analysis on the use of alternative raw materials as a source for cellulose production has also been performed.

Keywords: cellulose, invasive alien plants, biomass, alternative raw materials, packaging design

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Sono-Assisted TEMPO-Mediated Oxidation of Cellulose: Properties from Fibers to Nanofibrils

JAKA LEVANIČ, ANTTI HAAPALA

The production of nanocellulose is a process that is highly dependent on chemical pre-treatments to reduce the energy consumption in the fibrillation process. And no other process is as ubiquitous as TEMPO mediated oxidation which has already been adopted on an industrial scale in Japan. The introduction of surface charged groups provides electrostatic repulsion between the fibrils and electrostatic stabilization of the fibrils in dispersion. The process itself is well understood yet improvements are always possible since laboratory trials usually don't face the same challenges as industrial scale production. The potential improvements in the TEMPO-mediated oxidation process lie in increasing the process efficiency itself. The main motivation being higher throughput.

We have opted to increase the throughput by sonicating the reaction mix in a flow cell outside the main reactor. Ultrasonic cavitation is better suited for flow systems as it does not scale well, so sonicating large reactor vessels is out of the question. The ultrasonic cavitation at 20 kHz has almost a purely mechanical effect on the cellulose fibres in suspension as opposed to higher frequency ultrasonic cavitation that would introduce reactive species in the mix and influence the TEMPO-mediated oxidation that way. The mechanical effect of the ultrasonic cavitation can be observed by the increased swelling of the cellulose fibres due to shear forces

produced by asymmetric cavitation bubble collapse. With increased surface area comes an increase in reaction speed. Sonicated reaction mixes showed a pronounced increase in fibre swelling and carboxylic group content at shorter processing times. At the same time, we did not observe negative effects on the fibre morphology, such as release of excess amounts of fibre fines which would cause problems during work-up or cause noticeable material losses due to sonication induced fibrillation and losses during washing. The changes in the pulp were followed by automated optical analysis.

Furthermore, the ultrasonic cavitation also influenced the properties of the nanocellulose dispersion obtained from subsequent microfluidization. The sonicated samples exhibited higher optical clarity, higher elasticity in gels while also having somewhat lower viscosities. On nanoscale, ultrasonic cavitation helped the subsequent microfluidization in releasing better individualized nanofibrils as they had smaller diameters than in non-sonicated samples. Sonication also had no effect on the crystallinity properties of the nanocellulose, the observed slight reduction was a result of intense microfluidization that was used to produce the nanocellulose dispersion. Ultrasonic cavitation in the TEMPO-oxidized pre-treatment phase was shown to be a method that can increase the throughput in lab-scale by mechanical activation of pulps and enabling shorter processing times for TEMPO-mediated oxidation.

Keywords: Acoustic cavitation, TEMPO oxidation, Cellulose, Nanocellulose, Process efficiency

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References

Levanič, J., Svedström, K., Liljeström, V. *et al. (2022)* Cellulose fiber and nanofibril characteristics in a continuous sono-assisted process for production of TEMPO-oxidized nanofibrillated cellulose. *Cellulose* 29, 9121–9142

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»Green« Wrought Aluminum Alloys with an Increased Amount of Post-Consumed-Scrap

VARUŽAN KEVORKIJAN

The recycling of wrought aluminum alloys (WAAs) from end-of-life products (ELPs) is practiced in the aluminum industry only to a very limited extent. The obstacles are the lack of (i) appropriate chemical composition of the recycled melt and (ii) sufficient reliable sources.

To eliminate both these obstacles we designed and prototyped an Advanced Circular Loop (ACL) that makes it possible to obtain scrap suitable for the production of WAAs.

We found that the first obstacle can only be eliminated through the high-quality separation of scrap or with complete traceability of the alloys in the ELPs—during every phase of the circular management of aluminum. Additionally, we found that such traceability and high-quality separation of alloys can only be achieved by consistent disassembly of the ELPs into components. Therefore, in our prototype loop, described in this paper, we are exclusively disassembling rather than shredding the ELPs.

For the elimination of the second obstacle, it was essential to motivate the owners of the ELPs to keep the material, as far as possible, within a closed loop. As will be described, we took care of this with a properly designed closed-loop business model that properly rewards the owners of the ELPs for consistently keeping their products within the loop.

As a result, the ACL ensures more than two-thirds of the return of the WAAs from the ELPs to their producers.

The universal traceability was assured by introducing our own Digital Product Identification (DPI) concept. The tracking begins already at the stage of disassembling the ELP into its parts or components made from WAAs. The traceability concept ensures that the WAAs contained in the ELP within the loop are known by the alloy designation, the manufacturer, and the location of the alloy in the product, allowing them to be consistently separated. It can also contain rules for disassembling the ELPs into components and more detailed or specific instructions for separating them. The existing DPI in the prototype ACL for WWAs was built using ordinary QR codes. However, it could be easily supplemented with more advanced solutions if necessary.

Our innovation makes it possible to obtain scrap of the highest quality from ELPs, comparable to the quality of the return material. This material, with the right of first refusal given to the original producers, is generally returned to the original alloy manufacturer, and directly cast into wrought alloys ***with a carbon footprint and sustainability index chosen and defined by the customer***. With this aim in mind, we developed alloys for the automotive and aviation industries with a large proportion (>70%) of scrap based on end-of-life products and an appropriate production technology that allowed us to maintain the standard quality of the produced alloys.

Since the aluminum in an ELP has practically no carbon footprint, this results in considerable decarbonization and large savings in terms of resources and logistics, as well as reducing the dependence of aluminum-alloy producers on primary aluminum (PA) and alloying elements (AEs).

Keywords: recycling, advanced circular loop, end-of-life products, aluminum wrought alloys, carbon traceability, business model, footprint, sustainability, high added value

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Comparative Study of Life Cycle Impact Assessment Methods Applied to PET Bottle Production

DAMJAN KRAJNC, LIDIJA ČUČEK, ANNAMARIA VUJANOVIĆ, JAN PUHAR, YEE VAN FAN, PETAR VARBANOV, ZDRAVKO KRAVANJA

Life Cycle Impact Assessment (LCIA) is a crucial phase in Life Cycle Analysis (LCA), converting Life Cycle Inventory (LCI) data of studied systems into understandable impact categories to evaluate their environmental implications. Various LCIA methodologies are being developed to model the environmental impacts of emissions and waste. This research evaluates and compares several LCIA methods concerning their assessment of environmental impacts on a demonstrative study of polyethylene terephthalate (PET) bottle production.

The functional unit is defined as the packaging necessary for the filling and distribution of 1000 L of filled beverage (typical 500 ml container unit assessed). The reference flow of a product system includes the actual beverage packaging (bottle, labels, and closures), as well as transport packaging (corrugated trays, shrink-wrap for disposable containers). Data is sourced from Ecoinvent 3.8 database. OpenLCA software with CML 2001 method is used for modelling.

The study assesses environmental impacts using LCIA methods: TRACI, ReCiPe, IMPACT 2002+, ILCD, EPD, EN 15804 +A2, CML, and IPCC (for GWP 100). The impact categories considered are Abiotic Depletion, Terrestrial Acidification,

Marine Eutrophication, Stratospheric Ozone Depletion, and Global Warming Potential.

Results obtained through these methods reveal notable discrepancies (standard deviation (*SD*)), underscoring the importance of method selection during LCIA. For Abiotic Depletion, variations in impact are evident, but the average values indicate that approximately 3043 MJ of fossil fuels are depleted over the product life cycle (*SD* = 180 MJ). Terrestrial Acidification impacts demonstrate relatively similar values among methods, with 0.509 kg SO_2 eq. on average (*SD* = 0.068 kg SO_2 eq.). Limited data on Marine Eutrophication from five methods suggest PET bottles contribute on average to around 0.293 kg N eq. (*SD* = 0.240 kg N eq.). Minimal impact on Stratospheric Ozone Depletion is observed across all methods, contributing 0.516 g CFC-11 eq. (*SD* = 0.150 g CFC-11 eq.). Global Warming potential results exhibit consistency across methods, with an average impact of approximately 199.63 kg CO_2 eq. (*SD* = 5.77 kg CO_2 eq.). The analysis results are further enhanced by comparing them with the coefficient of variation (*SD*/*MEAN*), enabling a clearer comparison of results involving diverse units.

Prudent interpretation of LCIA results depends on the selected methodology; varying impact categories may yield different conclusions. Therefore, validating LCA study outcomes with multiple LCIA methods and adhering to impact assessment recommendations is advisable.

Keywords: life cycle impact, life cycle inventory, life cycle assessment, PET bottle production, openlca

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Bacterial Cellulose Membranes Enriched with Bioactive Compounds from Avocado Seeds

KAJA KUPNIK, MATEJA PRIMOŽIČ, ŽELJKO KNEZ, MAJA LEITGEB

Introduction: In recent years, biologically active materials have captured the focus of research and the use of bacterial cellulose membranes (BCMs) as carriers is one of the most interesting applications for the biomedical, pharmaceutical, cosmetic and food industries. Bacterial cellulose (BC) has been widely used because of its nontoxicity, hydrophilic nature, biocompatibility, and good mechanical and barrier properties, which grant its wide availability (Kupnik, 2020). However, BC itself has no antimicrobial and antioxidant activity, which are one of the most sought-after properties. To increase its applicability, BCM can be enriched with bioactive compounds. On the other hand, science is striving for a broader strategy for the transition to circular economy. Food wastes present a renewable resource that can be converted into value-added products and avocado (*Persea americana* L.) seeds are great source of biologically active compounds, which exhibit exceptional antimicrobial and antioxidant activity (Kupnik, 2023).

Methods: The production of BCMs by *Komagataeibacter hansenii* was performed using complex Hestrin and Schramm production medium. Bioactive compounds from avocado seeds were recovered using ethanol as solvent. Obtained BCMs were further enriched with bioactive compounds recovered from avocado seeds.

Additionally, their antibacterial activity was tested against *Escherichia coli* and *Staphylococcus aureus* using disc diffusion method.

Results: The results of the research showed successful production of antibacterially active BCMs enriched with compounds from avocado seeds.

Conclusions: The BCMs enriched with bioactive compounds from avocado seeds have shown great potential with their antibacterial effect for potential applications in biomedicine, food (e.g. food packaging), cosmetic (e.g. sheet masks), pharmaceutical (e.g. patches) industries.

Keywords: bacterial cellulose, nanocellulose, avocado seed, antibacterial, bioactive membrane

Acknowledgement

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References

Kupnik, K.; Primožič, M.; Kokol, V.; Leitgeb, M., 2020, Nanocellulose in Drug Delivery and Antimicrobially Active Materials. Polymers , 12, 2825.

Kupnik, K.; Primožič, M.; Kokol, V.; Knez, Ž.; Leitgeb, M., 2023, Enzymatic, Antioxidant, and Antimicrobial Activities of Bioactive Compounds from Avocado (*Persea americana* L.) Seeds. Plants , 12, 1201.

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Circular Construction – from Development of New Products to Circular Business Models

ALENKA MAUKO PRANJIĆ, PRIMOŽ PAVŠIČ, DAVOR KVOČKA, DRAGICA MARINIČ, ANA MLADENOVIČ, PRIMOŽ OPRČKAL

Construction sector (buildings and infrastructure, e.g. roads, railway tracks, water infrastructure) is one of the most resource, energy and water intensive sectors in Europe. It consumes almost half of all raw materials extracted (1.6 billion tonnes per year), 40% of the total energy (by buildings alone), one third of fresh water, it generates over one third of waste (37.5% in 2022 by mass) and emits 250 million tonnes of CO_2 (from building materials alone). Looking into the future the global annual production of the sand, gravel and crushed rock needed for construction activities will increase from 28 giga tonnes today to 55 giga tonnes in 2060 (OECD, 2019). European construction sector is also the second most important of the economic ecosystems in Europe bringing added value of 9.6% of the EU total and giving jobs to 29.8 million Europeans (EC, 2023).

The main objective of the CINDERELA project (EU H2020, 2018-20221) was to untap potential of the secondary raw materials (SRM), i.e., recycled waste, in construction industry. Through project several SRM-based construction products were developed as well as new recycling and construction technologies. These were demonstrated in large-scale projects around Europe, which were supported by new

digital one-stop-shop with on-line and off-line services called CinderOSS (for more information see www.cinderela.eu).

The main steps to turn waste into SRM-based construction products in the local and regional environments and developing a circular business case were identified as following: (i) identifying potential waste for secondary raw materials in your region (with the help of CINDERELA waste list) and quantifying/visualizing waste and materials flows based on (publicly) available waste data; (ii) assessing new, more sustainable, potential value chains and compare them with existing ones which are based on linear economy and use of primary raw materials; (iii) developing and testing SRM-based products; (iv) testing and improving pilot production lines; (v) and testing of products in real environment through construction, use and end-of-life phases. These steps should be all the time validated for environmental, economic and social impacts via Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) while assessing regulatory, technical and economic feasibility.

The ReBuilt project (Interreg Central Europe, 2023-2026, contract no. CE0100390) is further upscaling some of the CINDERELA solutions on the regional level of Central Europe. The main objective of project is to increases awareness and attractiveness of circular and digital construction through creation of education programme, upgrade and piloting of new solutions (technical and digital), upgrade demand-side measures, including green labeling, End of Waste criteria, Green Public Procurement (GPP) and through creation of first Central European Circular and Digital Construction Strategy which will be deployed through network of Regional Circular and Digital Construction Hubs.

Both projects in synergy with many other activities, in which Slovenian National Building and Civil Engineering Institute is involved are bringing significant positive impacts to Slovenian and Central European construction and therefore enhancing swift green (and digital) transition of EU construction industry and its ecosystems.

Keywords: circular construction, circular business model, secondary raw material, value chain, Life Cycle Assessment

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References

CINDERELA website, <https://www.cinderela.eu/> accessed 30 June 2023.

EC, 2023, Transition pathway for Construction, 74 pps, European Comission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs.

LIFE IP RESTART, < https://webgate.ec.europa.eu/life/publicWebsite/project/details/5813> accessed 30 June 2023.

OECD, 2019, Global Material Resources Outlook to 2060. Economic Drivers and Environmental Consequences, OECD Publishing, Paris.

ReBuilt website, https://www.interreg-central.eu/projects/rebuilt accessed 30 June 2023.

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Techno-Economic Model of Multimodal Transport

DAVID POUL, JIŘÍ GREGOR, MARTIN PAVLAS, YEE VAN FAN

With the current effort to reduce transport emissions, the shift in the transport of goods from road to rail or combination is expected on a larger scale. For this shift to have the expected results, it needs to be supported by detailed project planning and calculation. However, the current state of computational support with a focus on waste management is insufficient. Current models are not detailed enough and do not always include all important parts of the logistics chain. One can often come across models that are not connected to real infrastructure or include only general types of transport systems which is not possible to modify because the model will not work properly without further changes in calculations. Many simplifications result in inaccuracies that affect the evaluation quality. Therefore, creating an advanced techno-economic model of multimodal transport, which can evaluate in detail the technical, economic, and environmental demands of a given logistic chain is required.

The paper presents the techno-economic model of multimodal transport, focusing on road and rail transport. The model includes a vast database of transport systems for both types of transport, where the user can modularly assemble the resulting transport system. The primary focus is on intermodal systems, mainly ACTS and Innofreight systems. The database consists of all important parts required to operate these systems such as containers, container carriers, intermodal wagons, or handling equipment. Since the model is considered universal, the database further includes

transport systems for non-intermodal transport such as rigid chassis with different custom bodies, trailers, locomotives, and different types of good rail wagons. The user can also add new entries to the database which leads to more detailed specifications of considered transport systems based on user requirements or needs. The choice of transport system affects the following calculation and is thus an essential part of the model.

The evaluation of transport routes is based on real infrastructure for road and rail. The model consists of infrastructure for the Czech Republic primarily due to data infrastructure availability, but it can be further expanded by adding other states' networks.

The model comes with a detailed calculation of the speed profile based on physical principles, which leads to more accurate estimates of fuel consumption and related emissions production. To complete the logistic chain, the model includes the calculation for transfer stations, handling equipment, and others. The model includes an economic evaluation allowing analysis of the whole logistic chain of multimodal transport or performing the comparison of individual types of transport.

The paper's output is the creation of a poster describing the model, the usage of the model with the key areas where is beneficial to use it, and also how it can be incorporated into optimization tasks.

Keywords: techno-economic model, multimodal transport, intermodal systems, road transport, rail transport, transfer station, circular economy

References

ERYGANOV, I.; ŠOMPLÁK, R.; NEVRLÝ, V.; OSIČKA, O.; PROCHÁZKA, V. Cost-effective municipal unions formation within intermediate regions under prioritized waste energy recovery. Energy, 2022, 256, č. 124621, s. 1-12. ISSN: 0360-5442.

GREGOR, J.; PAVLAS, M.; ŠOMPLÁK, R. Transportation Cost as an Integral Part of Supply Chain Optimization in the Field of Waste Management. CHEMICAL ENGINEERING TRANSACTIONS, 2016, 56, č. 1, s. 1927-1932. ISSN: 2283-9216.

HEINOLD, Arne a Frank MEISEL. Emission rates of intermodal rail/road and road-only transportation in Europe: A comprehensive simulation study. Transportation Research Part D: Transport and Environment [online]. 2018, 65, 16 [cit. 2022-10-26]. ISSN 1361-9209.

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Sustainable Optimization of the Food Supply Chain Under Uncertainty

JAN DROFENIK, BOJAN PAHOR, ZDRAVKO KRAVANJA,
ZORKA NOVAK PINTARIČ

Food production is of strategic importance to humanity. Feeding a growing population in the face of emerging climate change and political uncertainties requires optimal allocation of land among different crops for human consumption and animal feed (Smith et al., 2022). To this end, a mixed-integer linear programming (MILP) model of the food supply chain was developed that optimizes land allocation, crop mass, and number of animals raised, while calculating environmental indicators such as greenhouse gas emissions and nitrogen balance, as well as social indicators such as the self-sufficiency level of each food, the macronutrient and energy value of the food produced, etc. (Drofenik et al., 2023). The model follows the guidelines of the Farm to Fork strategy (European Union, 2020), which aims to make the food system fair, healthy, and environmentally friendly. Therefore, the model enables a multi-objective optimization of the food chain that includes all three aspects of sustainable development (economic, social, and environmental). The basic version of the model assumes constant yields of agricultural crops, which in reality vary depending on weather conditions, seed quality, presence of weeds and pests, etc. As climatic conditions change rapidly, the negative effects of weather on crop yields are expected to increase (Corcoran et al., 2023). Therefore, the objective of

this paper is to demonstrate the integration of yield uncertainties into a food supply chain optimization model.

The study collected data on yields of the main agricultural crops in Slovenia between 2018 and 2021. Minimum, maximum and average yields for this period were determined, representing pessimistic, optimistic and average scenarios. As a first step, the food supply chain was optimized using a wait-and-see approach, which represents a hypothetical situation in which the optimal distribution of land and the quantities of food produced could be determined simultaneously. This means that the weather conditions and the values of the yields would have to be known at the time of sowing. Since this is not possible, a deterministic approach was adopted in which decision making occurs in two stages: the allocation of arable land is determined in the first stage before yields are known, and all other variables are determined thereafter in the second stage. In a third step, optimization was performed with a stochastic (here-and-now) approach, treating all scenarios simultaneously in a model that was transformed into a two-stage stochastic model with recourse. The results are compared with a Monte Carlo simulation. The expected value of perfect information is calculated, showing that it is worth investing in reducing uncertainty in yields, especially for crops that are less susceptible to weather and pests. The value of the stochastic solution is also determined, confirming the advantage of a stochastic approach over a deterministic approach.

Keywords: food, supply chain, mathematical optimization, sustainability, uncertainty, cultivation yields

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References

Corcoran E., Afshar M., Curceac S., Lashkari A., Raza M. M., Ahnert S., Mead A., Morris R., 2023, Current data and modeling bottlenecks for predicting crop yields in the United Kingdom, Frontiers in Sustainable Food Systems, 7, 1-23.

Drofenik J., Pahor B., Kravanja Z., Novak Pintarič Z., 2023, Multi-objective scenario optimization of the food supply chain – Slovenian case study, Computers & Chemical Engineering, 172, 108197.

European Union, 2020. Farm to Fork Strategy. http://bit.ly/44xutKM (accessed 19. 7. 2023)

Smith N. W., Fletcher A. J., Millard P., Hill J. P., McNabb W. C., 2022, Estimating cropland requirements for global food system scenario modeling, Frontiers in Sustainable Food Systems, 6, 1-15.

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Is the Plastic Conscious Society Enough to Stop the Pollution?

UROŠ NOVAK, MIRICA KARLOVITS, VESNA KURALT, BLAŽ LIKOZAR

In 2023 the generation of plastic waste exceeds the capacity of waste management, leading to environmental pollution on 28th of July. (https://plasticovershoot.earth/report-2023/) The plastics production is expected to double in the coming years, which will most probably led to triple the volume of plastic pollution. There are several factors, which greatly contribute most direct it's the lack of sufficient waste management systems to properly process plastic after it has been used. Although this seems a problem easy to fix the real alternatives for plastics have not been seen yet in the horizon.

The focus of plastic pollution reduction strategies can be broadly partitioned into upstream (preconsumption, such as reducing demand) and downstream (postconsumption, such as collection and recycling) measures. In the analysis of possible scenarios from Lau et al (2020) modeled that urgent and coordinated action combining pre- and postconsumption solutions could reverse the increasing trend of environmental plastic pollution. Although no silver bullet exists, 78% of the plastic pollution problem can be solved by 2040 through the use of current knowledge and technologies and at a lower net cost for waste management systems compared to current business as usual.

The perspective in the recycling of the plastics, where market research data predicts significant growth in the plastics recycling industry over the next decade. The global market is expected to expand by over 50% from USD 41.24 billion in 2022 to USD 66.66 billion in 2030.

Societal awareness of the environmental impact of plastic waste, government regulations, and future options for recycling of plastic waste are driving this growth. However, limited infrastructure and investment in developing countries pose challenges. Some advanced technologies like pyrolysis and chemical recycling offer opportunities to been able to close the loop from plastic release to the environment. (https://waste-management-world.com/resource-use/plastics-recycling-market-set-to-grow-big/)

The earlier companies, cities, and countries plan ahead and prepare themselves for the predictable future, the better their chance of thriving. Taking into account the planet EU Green deal envision step towards new logic resilience and sustainability through exploring zero- waste streams not only to replace current practice but foremost pursue a way of delivering new value products and energy by closing the loops, reducing the material and emission footprint and protecting the environment and resources for the future generations.

The main outcome of this is to provide a starting point for future conversation. Can the plastic will be replaced by "nothing" will be presented. Aiming toward each individual conscious decision and explore social, environmental and bossiness perspectives.

As special cases our studies for building a circular bioeconomies from the waste being available in quantities for commercial valorisation, will be exemplified. The research group of Bioplastic, biocomposites and zero-waste technologies having more than 10 highly ambitious individuals, combining the social science, science, design and engineering in an interdisciplinary solution based working groups. Thus being one of the leading R&D labs in the region, where besides scientific excellence a start-up development is included as well demonstrated in multiple EU projects. (https://bioapp-plasticfree.eu/)

Keywords: plastic pollution, zero-waste, recycling, plastic conscious society, biomaterials

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References

EA - Environmental Action (2023) Plasteax free dataset - all packaging and generic polymer, model version 2.0 (PLASTEAX.org)
https://waste-management-world.com/resource-use/plastics-recycling-market-set-to-grow-big/
https://bioapp-plasticfree.eu/
Lau et al., Science 369, 1455–1461 (2020)

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Large-Scale Demonstrations of Constructing with SRM-Based Construction Materials

PRIMOŽ PAVŠIČ, ALENKA MAUKO PRANJIĆ, ANA MLADENOVIČ, PRIMOŽ OPRČKAL, TOMISLAV PLOJ

There is an ever-growing demand for raw materials in urban construction. To address this issue sustainably and in economically acceptable way, innovative approaches are required. One such approach involves utilizing Secondary Raw Materials (SRM) derived from recycling construction, industrial, mining, and certain municipal wastes. The CINDERELA project (EU H2020, 2018-20221) aimed, among other things to demonstrate, through large-scale pilot projects, the potential of using SRMs with new recycling and construction technologies, as well as the reuse of construction products as a suitable alternative to the use of virgin materials from natural sources.

One of the pilot demonstrations took place at Dogoše abandoned gravel pit, located 8 km southeast of the Maribor city center, Slovenia.

At the construction site were as part of the construction project incorporated different SRMs. Recycled aggregates from mixed construction wastes, recycled natural aggregates, a mix of recycled asphalt, and recycled asphalt stabilized with coal ash were used instead of virgin natural aggregates for the road's upper bearing layers. The road was built on a compacted subgrade which represented a geotechnical fill,

consisting of compacted recycled mixed construction and demolition waste aggregates (CDW), used in the revitalization of the old gravel pit. All the SRMs used and the structural quality of the constructed road layers met the requirements specified in the national Technical Specification for Public Roads in Slovenia (DRSC, 2003a, DRSC 2003b).

In the construction of an embankment for noise protection, , various recycled materials were utilized, including reclaimed asphalt pavement, recycled CDW aggregate, recycled excavated soil, and a geotechnical composite composed of Recycled Heavy Fraction from processing of mixed municipal waste and coal ash from thermal plant (Oprčkal et al., 2022).

In addition to ensuring structural safety, the environmental aspect was also considered and legal demands were met. For this purpose, the chemical parameters of the SRMs were monitored and the results showed no negative impact on the environment.

To establish recycling plant at the Dogoše, a plateau with separation walls for the storage of recycled aggregate and a small facility, which will serve as an office and presentation room was built. For the construction of the partition walls and the building structure, "green concrete blocks" with dimensions of 1,8 x 0,6 x 0,6 m were produced, from recycled concrete aggregates. The building structure was partially constructed with reused structural wood beams and reused structural wood panels. The first floor of the building also represents the reuse of various materials from the selective demolition. It consists of reused structural wood elements, while the roof is covered with reused roof tiles. Part of the facade is made from old window, while another part is made of reused and restored wooden planks and insulating material – called "Landapore". Recycled building materials were also used for interior elements. The facility is connected to municipal infrastructure and utilizes reused wastewater from an on-site wastewater treatment plant (INTERREG, 2014-2020).

A large–scale demonstration at the Dogoše site has shown that recycled SRMs and reused products, as well as discarded construction products, can be utilized in construction, thereby minimizing the use of natural raw materials and resources.

Keywords: secondary raw materials, environment, sustainability, construction, circular economy

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References

CINDERELA website, <https://www.cinderela.eu/> accessed 30 July 2023.
DRSC, TSC 06.100 : 2003, Kamnita posteljica in povozni plato, 2003.
DRSC, TSC 06.200 : 2003, Nevezane in nosilne obrabne plasti, 2003.
INTERREG CENTRAL EUROPE City Water Circles, website, <https://programme2014-20.interreg-central.eu/Content.Node/Secondary-raw-material-from-wastewater-in-Maribor.html> accessed 30 July 2023.
Oprčkal P., Mauko Pranjić A., Mladenovič A., Meža S., Ilenič A., Šprinzer M., 2022, Gradbeni kompozit iz ostanka mešanih komunalnih odpadkov po mehanski obdelavi, postopek njegove izdelave in vgradnje : patent SI 26039 A, 2022-02-28. Ljubljana: Urad Republike Slovenije za intelektualno lastnino, 2022.

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Waste Nuclear Radiation Utilization for Hydrogen Production

ANŽE PRAŠNIKAR, BRIGITA HOČEVAR, ANŽE JAZBEC, LUKA SNOJ, BLAŽ LIKOZAR

Hydrogen has advantages, but its main disadvantages lie in the difficulties of long-term storage. Methanol is a promising option because of its liquid form, its potential for further chemical conversion and its ability to be produced from CO_2. The integration of power plants with other energy-intensive sectors such as cement, ceramics and chemicals requires a circular balance of renewables, hydrogen and CO_2 through industrial symbiosis. Nuclear power plants have traditionally been associated with hydrogen production. Existing studies focus on the economics, safety and technical integration of H_2 production, storage and use at power plant sites (Taljan et al., 2008, Cerri et al., 2010, Avsec et al. 2011). However, little attention has been paid to the use of radiation waste for the irradiation of hydrogen carriers such as methanol. This study aims to evaluate the feasibility of radiolysis-initiated catalytic methanol conversion reactions using known methanol steam reforming catalysts and materials that interact with radiation. The potential for broader industrial symbiosis is also being investigated.

To carry out the experiments, the catalyst samples were weighed and mixed with the methanol solution in quartz glasses, which were purged with helium and sealed. The irradiations were carried out in the research reactor of the Jožef Stefan Institute TRIGA Mark II under various conditions. After irradiation, the samples were kept at low temperature to ensure the decay of the neutron-activated elements. The gas

and liquid samples were analysed by GC (gas chromatography) and GC-MS (GC coupled to mass spectrometry) to determine the concentrations of liquid and gaseous compounds. Temperature measurements and pressure tests were also carried out.

The study investigates the influence of different catalysts, such as TiO_2, $Cu/ZnO/Al_2O_3$, Pt/SiO_2 and Pd/In_2O_3, on the yield of hydrogen gas. The results show that the irradiation itself causes a hydrogen yield of 2.9 (G-yield), with TiO_2 increasing the yield significantly. A comparison between different radiation sources shows some difference in the yields obtained by gamma-only irradiation and gamma+neutron irradiation. In addition, a linear relationship was observed between compound production and absorbed dose rate. The material characterisation of the catalysts shows that TiO_2-P25 is mainly composed of the anatase phase, which is active for the photocatalytic MeOH conversion. The presence of high-Z elements (Pb, Pt or Pd) did not increase methanol conversion based on hydrogen and formaldehyde yields.

Finally, we have also explored the industrial applicability of the results, including product purity considerations for applications such as fuel cells and ammonia production. Several methods are proposed to improve product purity, such as the use of interceptors and CO methanation. We have also investigated heat balance calculations and scale-up possibilities for the use of waste radiation for MeOH radiolysis.

In general, the use of nuclear energy is subject to the highest safety standards, which can be maintained when exploiting waste radiation energy.

Keywords: radiolysis, methanol, hydrogen, waste utilization, carbon dioxide, nuclear energy

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References

Avsec J., Virtič P., Žagar T., Štrubelj L., 2011, Economy analysis of electricity production from

hydrogen in combination with nuclear power plant, American Society of Mechanical Engineers Power Conference, 2, 345–352.

Cerri G., Salvini C., Corgnale C., Giovannelli A., De Lorenzo Manzano D., Martinez A.O., 2010, Sulfur-Iodine plant for large scale hydrogen production by nuclear power. International Journal of Hydrogen Energy, 35, 4002–4014.

Taljan G., Fowler M., Cañizares C., Verbič G., 2008, Hydrogen storage for mixed wind-nuclear power plants in the context of a Hydrogen Economy. International Journal of Hydrogen Energy, 33, 4463–4475.

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Degradation of Antibiotics in Wastewater by Immobilized Laccase

MATEJA PRIMOŽIČ, ANA VRSALOVIĆ PRESEČKI, DINO SKENDROVIĆ, ŽELJKO KNEZ, YILMAZ YÜREKLI, MAJA LEITGEB

Introduction: Antibiotics are one of the most prescribed and used classes of drugs in the world used mainly in human and veterinary medicine. They are also used in livestock production, such as poultry farms and aquaculture to prevent diseases and promote growth (Becker et al., 2016). The human body often does not fully metabolize antibiotics, consequently they are released into the aquatic environment, where they can have a negative effect on non-target species. More recent studies show that the amount of antibiotics wastewater is increasing, which poses a risk to the environment. Classical remediation techniques of water cleaning such as membrane adsorption are able to separate pollutants from water, yet the separated pollutants require additional treatment or disposal (Karthik et al., 2021). Several different technologies have been proposed for the removal of antibiotic residues during wastewater treatment, such as ozone and advanced oxidation processes, but these methods tend to produce toxic byproducts (Russell and Yost, 2021). Therefore, there is a need for efficient, non-toxic treatment options such as enzymatic degradation. Degradation of the antibiotic ciprofloxacin (CIP) was performed using the immobilized enzyme laccase in the form of cross-linked enzyme aggregates (Lac-CLEAs).

Methods: The Lac-CLEAs was prepared by simple immobilization method involving precipitation of the enzyme from aqueous buffer using different precipitation solvents (e.g., ethanol, 1-propanol) followed by cross-linking of aggregates of enzyme molecules by glutaraldehyde. The effect of addition of bovine serum albumin (BSA) or egg albumin (EA) as a proteic feeder on Lac-CLEAs activity was studied.

Results: The highest activity (76%) of immobilized laccase in the form of Lac-CLEAs was achieved when BSA, as proteic feeder, and absolute ethanol, as precipitation reagent, were used. On the contrary, better stability was demonstrated by Lac-CLEAs synthesized using EA, as after 11 cycles of reuse, more than 50% of the initial activity was retained. In contrast, Lac-CLEAs synthesized using BSA already lost more than 50% of their initial activity after only two reuses. Degradation of CIP in a model system using Lac-CLEAs and the mediator 4-hydroxy-3,5-dimethoxybenzaldehyde (SA) was successfully performed.

Conclusions: CIP is one of the major polluters of wastewater. Its degradation is also successful using green approaches, such as the use of immobilized enzymes. Enzyme immobilization in the form of CLEAs is a carrier-free immobilization technique and is a cost-effective method. This technique has been shown to be very effective with a wide variety of enzymes. Lac-CLEAs proved to be a successful biocatalyst for CIP degradation.

Keywords: immobilization, laccase, degradation of antibiotics, wastewater treatment

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References

Becker, D., Varela Della Giustina, S., Rodriguez-Mozaz, S., Schoevaart, R., Barceló, D., de Cazes, M., Belleville, M.-P., Sanchez-Marcano, J., de Gunzburg, J., Couillerot, O., Völker, J., Oehlmann, J., Wagner, M., 2016. Removal of antibiotics in wastewater by enzymatic treatment with fungal laccase – Degradation of compounds does not always eliminate toxicity. Bioresource Technology 219, 500–509. https://doi.org/10.1016/j.biortech.2016.08.004

Karthik, V., Kumar, P.S., Vo, D.-V.N., Selvakumar, P., Gokulakrishnan, M., Keerthana, P., Audilakshmi, V., Jeyanthi, J., 2021. Enzyme-loaded nanoparticles for the degradation of wastewater contaminants: a review. Environ. Chem. Lett. 19, 2331–2350. https://doi.org/10.1007/s10311-020-01158-8

Russell, J.N., Yost, C.K., 2021. Alternative, environmentally conscious approaches for removing antibiotics from wastewater treatment systems. Chemosphere 263, 128177. https://doi.org/10.1016/j.chemosphere.2020.128177

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Residues of Pharmaceuticals in Drinking and Wastewater

URŠKA ROZMAN, BOŠTJAN KRIŽANEC, DAVID HALOŽAN, SONJA ŠOSTAR TURK

Pharmaceuticals are synthetic or natural chemicals that can be found in prescription drugs, over-the-counter drugs, and veterinary drugs. In recent decades, traces of pharmaceutical products have appeared in the water cycle, including surface water, wastewater, groundwater and, to a lesser extent, in drinking water. Advances in analytical technology have been a key factor driving their increased detection. Their presence in water, even at very low concentrations, has raised concerns among the professional public regarding possible risks to human health. The presence of drug residues in wastewater and drinking water is closely related to the prescription and consumption of drugs in an individual area.

In the research, we analysed data on the consumption of medicines in 2021, which are prescribed in hospitals and outpatients in Slovenia. We will take a sample of drinking water and wastewater at the Central Water Treatment Plant Ptuj, and with the method of HPLC/MS/MS determine the presence of selected pharmaceuticals.

The analysis of drug consumption data showed that rosuvastatin, which belongs to drugs for changing serum lipid levels, was the most frequently prescribed outpatient drug, while in hospitals the consumption of vitamin D and its analogues was prescribed most frequently.

Although current published risk assessments indicate that trace concentrations of pharmaceuticals in drinking water pose a very low risk to humans, there are gaps in knowledge regarding the assessment of risks associated with long-term exposure to low concentrations of pharmaceuticals and combinations of different drug mixtures. Future research in these areas could be useful to better characterize the potential health risks of long-term, low-level exposure to pharmaceutical products, especially for sensitive sub-populations. One of the key challenges in assessing exposure to pharmaceutical products through drinking and wastewater and assessing possible risks to human health. It is also very important to study new possibilities for wastewater treatment procedures, which we want to investigate in the continuation of the research.

Keywords: pharmaceuticals, wastewater, drinking water

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Advanced Data Analytics in Industry for Enabling Circular Economy from Within

MATEJ EMIN, DREJC KOPAČ

The adoption of circular production practices in industry necessitates a systematic and efficient approach to explore the relationship between multiple input variables (factors or parameters) and key output variables (responses or measurements). This presentation introduces the integration of Design of Experiment (DoE) and predictive modelling as a powerful framework for establishing a circular production in industry, with a particular focus on reliability analysis (Goos and Jones, 2011). DoE enables scientists, engineers, and process operators the most effective way to collect data and discover cause-and-effect relationships, while predictive modelling techniques facilitate the development of statistical models to predict results based on factors and their combined effects.

In addition to facilitating the understanding of cause-and-effect relationships, DoE empowers researchers to design the most efficient custom experiments by reducing the number of trials required (Jones and Montgomery, 2019). This saves time and resources, thus enabling the systematic exploration of various factors and their interactions, optimizing the circular production process. Furthermore, the integration of predictive modelling techniques, such as the development of statistical models and the creation of digital twins, enhances the ability to predict outcomes based on factors, enabling informed decision-making.

Reliability assessment plays a critical role in circular production, particularly for repairable and non-repairable systems. Statistical methods complement traditional engineering approaches by providing insights into the reliability of systems and facilitating proactive maintenance planning. The use of modern software reliability analysis tools offers comprehensive capabilities to analyze degradation information and predict failure occurrences, enabling businesses to prevent failures, improve warranty performance, and optimize maintenance strategies (Escobar and Meeker, 1998).

By combining the strengths of DoE and predictive modelling, industrial practitioners and researchers can effectively introduce circular production practices, optimize resource allocation, and minimize waste generation. Our presentation demonstrates how the integration of DoE and predictive modelling, with a specific emphasis on reliability analysis using software reliability analysis tools, can enhance the implementation of circular production in industry (Lamberti et al., 2022). Real-world case studies are presented to illustrate the benefits of such approach, showcasing improved system reliability, reduced maintenance costs, and enhanced warranty performance. The findings contribute to the advancement of circular production strategies and provide valuable insights for industrial decision-makers, researchers, and practitioners seeking to drive sustainable transformations in industrial processes.

In addition to the theoretical background, we will present a case study on how we have implemented an advanced data analytics capability in the SIJ – Slovenian Steel Group, where researchers are now using the above-mentioned principles to develop new products and optimize the production processes (Mitrović, 2023).

Keywords: advanced data analytics, circular production, Design of Experiments (DOE), product reliability, production process optimisation

References

Escobar, L.A. and Meeker, W.Q. Statistical Methods for Reliability Data, 1998, Wiley.
Goos, P. and Jones, B. Optimal Design of Experiments: A Case Study Approach, 2011, John Wiley Sons Inc.
Escobar, L.A. and Meeker, W.Q. Statistical Methods for Reliability Data, 1998, Wiley.

Lamberti, F., et al. Design of Experiment: A Rational and Still Unexplored Approach to Inorganic Materials' Synthesis, 2022, Sustainable Chemistry, 3(1), 114-130.
Mitrović, D. Napredna analitika za kompleksne industrijske izzive, 2023, Revija SIJ, Marec, 1, 22-24.

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Surface Properties of Recycled Materials Produced from Disposable Surgical Masks

ALEN ERJAVEC, JULIJA VOLMAJER VALH

With the frequent outbreaks of contagious viral diseases in the last two decades (Ebola, Sars, COVID -19...) and the air pollution in large cities, the production and use of disposable surgical masks (DSMs) have increased enormously (Akber Abbasi et al., 2020; Akhbarizadeh et al., 2021; Dharmaraj et al., 2021; Remic et al., 2022; Spennemann, 2022). With the huge use of DSMs came also huge production of special kinds of waste. According to the European Union directives, it is necessary to look for possible solutions in accordance with the hierarchy of waste management. Depending on the materials used in DSM and considering the hierarchy, the first best choice is to recycle the waste. DSM consists of three main components: - ear loops, nose wire, and a three-layer filter part made from nonwoven and melt-blown textiles. Since these kinds of waste are mainly thermoplastic materials, mechanical thermal processing makes the most economical and energetic sense (Battegazzore et al., 2020; Erjavec et al., 2022; Ramasamy and Subramanian, 2023). For secondary materials, mechanical properties are one of the first properties to be tested. However, a comprehensive analysis of the recovered materials requires a series of analyses. Therefore, this study investigated the extended surface properties of the produced recyclates. The recyclates were produced with a twin screw extruder (Thermo Scientific Process 11) with eight temperature zones. The obtained filament was granulated and used to produce test samples by injection

moulding (Thermo Scientific Haake Mini Jet Pro). 3 different materials were produced - recycled material from the filtering 3-layer part of the DSM, recycled material from the ear loops, and mixed material from the filtering part and the ear loops in the weight ratio as they are in the DSM. The test specimens were made according to the standards of a 3-point bending test in a diameter of 60 x 10 x 1 mm. The surface properties of all 3 recyclates were then investigated using goniometry analysis (Dataphysics OCA 35 goniometer) to determine the material's hydrophobicity and surface free energy. The contact angle was calculated using the modified Washburn equation and then the geometric mean equation (Owens-Wendt-Rabel-Kaeble approximation) was used to determine the surface free energy. Using SurPASS 3 (Anton Paar GmbH, Austria) with an adjustable gap cell to accommodate samples with a flat surface, zeta potential measurements were performed. The pH dependence of the zeta potential was determined in the pH range from 2.5 to 9. In addition to understanding the distribution of different materials in test specimens micro FTIR (Perking Elmer Spectrum 3 with Spotlight 200i) mapping has been carried out. It has been found, that recyclate obtained from ear loops is more hydrophilic in comparison with the other two materials. Also, the surface free energy and zeta potential are both significantly lower in the case of recycled material obtained only from ear loops. With micro FTIR mapping, the distribution of different materials in test samples was explained.

Keywords: recycling, disposable surgical mask, extrusion, micro FTIR mapping, surface properties

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References

Akber Abbasi, S., Khalil, A.B., Arslan, M., 2020, Extensive use of face masks during COVID-19 pandemic: (micro-)plastic pollution and potential health concerns in the Arabian Peninsula, Saudi J Biol Sci 27(12), 3181-3186.

Akhbarizadeh, R., Dobaradaran, S., Nabipour, I., Tangestani, M., Abedi, D., Javanfekr, F., Jeddi, F., Zendehboodi, A., 2021, Abandoned Covid-19 personal protective equipment along the Bushehr shores, the Persian Gulf: An emerging source of secondary microplastics in coastlines, Mar Pollut Bull 168, 112386.

Battegazzore, D., Cravero, F., Frache, A., 2020, Is it Possible to Mechanical Recycle the Materials of the Disposable Filtering Masks?, Polymers 12(11), 2726.

Dharmaraj, S., Ashokkumar, V., Hariharan, S., Manibharathi, A., Show, P.L., Chong, C.T., Ngamcharussrivichai, C., 2021, The COVID-19 pandemic face mask waste: A blooming threat to the marine environment, Chemosphere 272, 129601.

Erjavec, A., Plohl, O., Zemljič, L.F., Valh, J.V., 2022, Significant Fragmentation of Disposable Surgical Masks—Enormous Source for Problematic Micro/Nanoplastics Pollution in the Environment, Sustainability 14(19), 12625.

Ramasamy, R., Subramanian, R.B., 2023. Recycling of disposable single-use face masks to mitigate microfiber pollution, Environmental Science and Pollution Research 30(17), 50938-50951.

Remic, K., Erjavec, A., Volmajer Valh, J., Šterman, S., 2022, Public Handling of Protective Masks from Use to Disposal and Recycling Options to New Products, Journal of Mechanical Engineering, 68(4), 9.

Spennemann, D.H.R., 2022, COVID-19 Face Masks as a Long-Term Source of Microplastics in Recycled Urban Green Waste, Sustainability 14(1), 207.

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6TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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Hydration of Ashes from Different Incineration Processes

VESNA ZALAR SERJUN, MARIJA ĐURIĆ, MATEJA ŠTEFANČIČ,
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Detailed knowledge of the progression of hydration of recycled materials is crucial for the technically efficient and economically viable large-scale utilization of industrial residues in green construction materials. Ashes from incineration processes vary in their characteristics, including phase and chemical composition, pozzolanic activity, amorphous phase content, and physical properties. The activity of ashes is vital in evaluating their potential as (binder) materials in civil engineering applications, resulting in the formation of cementitious compounds and improved mechanical properties. Taking into account the varied composition of ashes depending on their origin and collection processes, this study attempted to define their cementitious hydration products at different time intervals, which directly impact their suitability for civil engineering applications.

Eight different types of ashes were analysed for their phase composition and time dependent hydration process. Analysed were ashes from: coal combustion, co-combustion, combustion of biomass and paper mill pulp, and solid waste incineration. Pastes were prepared by mixing ashes with water in a 2 : 1 ratio and analysed at 6 different time intervals (2, 7, 14, 56, 90, and 180 days). Additionally, two ashes with lower activity level were examined in a binary system, where they were mixed with ash possessing higher reactivity (in a 75 % to 25 % ratio). The analyses were performed by X-ray powder diffraction.

The results of the performed analysis revealed that the most significant crystalline hydration products of all the analysed samples consisted of calcium aluminates hydrates. Ettringite was present in all the ashes, with the exception of the ash which was obtained by combusting a mixture of coal and biomass, and of both of the paper mill sludge ashes. In the case of the latter two ashes, a clear transition of hemicarboaluminate to monocarboaluminate was observed as the duration of the hydration period increased. The formation of the Friedels salt was observed only after 14 days of hydration of the municipal solid waste incineration ash.

The analysis revealed that the primary crystalline hydration products present in all the examined ashes were various phases of calcium aluminates hydrates, phases typical for cementitious system. At least partial hydration activity of all the investigated ashes was confirmed. The formation of a higher quantity of hydration products over time indicated the activation of less reactive ashes when blended with more reactive one.

These results further emphasise the importance of a systematic analysis of all parameters critical for determining the activity properties of the ashes. Specifically, the detailed characterization of the amorphous phase will be conducted in the subsequent stages of the ongoing research work.

Keywords: incineartion ashes, pozzolans, hydration, X-ray diffraction, reaction products

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Chemical Composition and Bioactivity of Cembran Pine Wood Waste Extracts

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Pine wood is utilised in all major industries, that produce wood processing residues. It is important to implement a biorefinery concept for the valorization of pine wood, which is a sustainable process for the use of biomass to fully utilise the wood material (Herrero & Ibañez, 2018). An important part of the biorefinery approach is to extract value-added components from pine wood residues through material recycle/reuse networks. In this way, bioactive compounds can be obtained that are used in pharmaceutical and cosmetic products, and for food fortification and preservation (Mármol et al., 2019). It is important to use environmentally friendly and sustainable processes, focusing on the use of supercritical fluids for the extraction of high value-added products from natural sources (Herrero & Ibañez, 2018). Carbon dioxide is the most commonly used because it is non-toxic, safe, and the critical temperature is low (Ferreira-Santos et al., 2020).

In this study, wood residues from furniture production of *Pinus cembra* L. were used as a raw material for supercritical CO_2 extraction of essential oils. Experiments were performed with high (HP) and medium (MP) extraction pressure. The GC/MS analysis was performed on the extracts and on commercially available cembran pine oil (reference R). In addition to the determination of volatiles, their relative

concentration to an internal standard and the TVOC value were also determined. The R sample has a much higher TVOC content than the samples extracted with CO_2. Tricyclene, o-cymene and α-phellandrene were detected in the HP and MP, whit o-cymene having the highest TE value. Hexanal was detected only in HP. Antioxidant activity determined by DPPH, ABTS and FRAP assays showed stronger activity of HP and MP, although without significant difference between them, but better antioxidant activity in HP determined by DPPH. The sample R showed lower antioxidant activity compared to the samples HP and MP, although the TVOC value was 75 times higher. The antimicrobial activity of the samples was determined as MIC and MBC/MFC for different groups of microorganisms. The best antimicrobial activity with the lowest MICs was found in MP followed by HP. Additionally, the inhibition of bacterial signalling and adhesion was analysed on a model bacterium *Campylobacter jejuni*. The effect of cembran pine preparations at subinhibitory concentrations on intercellular signalling of *C. jejuni* was indirectly verified by measuring the emitted bioluminescence of the biosensor strain *Vibrio harveyi*, which showed that all cembran pine preparations reduced intercellular signalling and adhesion of *C. jejuni*. The trend for both parameters shows that the activity of our samples increases from sample R to MP, which was also confirmed by the correlation test. Cembran pine wood waste extracts have shown good effect against *C. jejuni* intercellular signalling as well as against *C. jejinu* adhesion, indicating that cembran pine wood waste extracts have potential against complex bacterial properties important for biofilm formation.

Keywords: wood residues, cembran pine, essential oils, antioxidant, antimicrobic, CO_2 extraction

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References

Apetrei C. L., Tuchilus C., Aprotosoaie A. C., Oprea A., Malterud K. E., Miron A., 2011, Chemical, antioxidant and antimicrobial investigations of *pinus cembra* L. bark and needles, Molecules, *16*(9), 7773–7788.

Ferreira-Santos P., Zanuso E., Genisheva Z., Rocha C. M. R., Teixeira J. A., 2020, Green and

sustainable valorization of bioactive phenolic compounds from pinus by-products. Molecules, 25(12).

Ghadiriasli R., Mahmoud M. A. A., Wagenstaller M., van de Kuilen J. W., Buettner A., 2020, Molecular and sensory characterization of odorants in Cembran pine (*Pinus cembra* L.) from different geographic regions. Talanta, 220(July), 121380.

Grote V., Frühwirth M., Lackner H. K., Goswami N., Köstenberger M., Likar R., Moser M., 2021, Cardiorespiratory interaction and autonomic sleep quality improve during sleep in beds made from *pinus cembra* (Stone pine) solid wood. International Journal of Environmental Research and Public Health, 18(18).

Herrero M., Ibañez E., 2018, Green extraction processes, biorefineries and sustainability: Recovery of high added-value products from natural sources. Journal of Supercritical Fluids, 134, 252–259.

Mármol I., Quero J., Jiménez-Moreno N., Rodríguez-Yoldi M. J., Ancín-Azpilicueta C., 2019, A systematic review of the potential uses of pine bark in food industry and health care. Trends in Food Science and Technology, 88, 558–566.

Schuster J. J., Bahr L. A., Fehr L., Tippelt M., Schulmeyr J., Wuzik A., Braeuer A. S., 2018, Online monitoring of the supercritical CO_2 extraction of hop. Journal of Supercritical Fluids, 133, 139–145.

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LIFE HIDAQUA: Sustainable Water Management in High Water Demanding Industries

MIREIA MESAS, SARA SERŠEN, CARLOS PÉREZ, SANJA MARKEŽIČ, JURE HOČEVAR, RADMILA MILAČIČ, PRIMOŽ OPRČKAL

The LIFE Hidaqua project is aims to demonstrate a sustainable water management in industry by the use of advanced treatment system that enables the simultaneous recycling and reclamation of industrial wastewater, along with the utilization of alternative water sources such as brackish and rainwater. The project solution employs combination of technologies like ultrafiltration and reused or regenerated reverse osmosis membranes, in conjunction with an innovative interactive Decision-Making Tool, which in one package provides the most efficient and sustainable water management solution. Other advanced technologies, like for example electro-dialysis reversal system was also tested on a laboratory scale, however it was found to be less effective for treatment of this specific type of industrial wastewater. In the initial stages of the project, different technologies were tested and optimized at bench scale at EURECAT facilities in Spain. Bench scale tests were carried out using real industrial wastewater and brackish water samples provided by HIDRIA.

In the first step it was decided to combine brackish water and industrial wastewater streams in a 1:1 ratio. Moreover, to improve the overall Oil and Grease (O&G) removal, a pre-treatment step with dissolved air flotation (DAF test) was introduced to industrial wastewater to reduce as much COD as possible before mixing it with

brackish water. The optimal pretreatment conditions found were 6 bar and 60% recirculation and no flocculant in DAF process. After both streams being mixed a coagulation/flocculation treatment is applied to remove most of the turbidity and metal content. With this treatment, a removal higher than 90% for O&G was achieved and over 80% for COD and turbidity values. The optimal pre-treatment conditions that were found were: 6 bar and 60% recirculation and no flocculant in DAF process; 5 ppm of coagulant and 0.5 ppm of flocculant for the coagulation/flocculation step with the mixed water.

Experiments on the laboratory scale have shown that the system is capable to remove contaminants from industrial wastewater (high content of oils and grease, with an average Chemical Oxygen Demand (COD) value of 20,000 mg O2/L with approximately 95% efficiency. It can treat approximately 4000 m3 of polluted water annually while simultaneously utilizing alternative water sources. As a result, the system produces approximately 24 m3 of purified water each day, with a conductivity of less than 0.6 mS/cm.

The introduction of "Zero-Liquid-Discharge" and "Zero-Waste" technologies will enable the complete recycling of all waste generated during the water treatment process. By adopting an innovative approach, the implementation of an advanced solar evaporation (ASE) pond, designed in the form of a greenhouse, efficiently captures solar heat to facilitate the intensive evaporation of waste product – brine. The process leads to the generation of salt products, while the remaining waste – sludge will be repurposed and recycled to create building composites, forming ready-to-use construction materials. The system predicts approximately 0.5 tons of salt and 1 ton of construction composites per year.

The water treatment system prototype was installed at HIDRIA factory in Koper in December of 2022 (Figure 1). Optimization of the operational parameters are currently in progress, and it is expected that the system will be fully operational in the next two years.

Figure 1: LIFE Hidaqua prototype for sustainable water management at the Hidria factory in Koper, Slovenia.
Source: own.

Keywords: sustainable, water, manageme nt, Zero- Liquid- Discharge, Zero-Waste, technology, industrial, wastewater, water, treatment, recycling.

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Smart, Recyclable and Repairable Composites

ARUNJUNAI RAJ MAHENDRAN, SIVA KAYLASA SUNDARI,
GÜNTER WUZELLA, HERFRIED LAMMER

Composites, once they reach the end of their useful life, pose a significant environmental concern. Recycling these composites aligns with the principles of the circular economy. In this study, polyimine-based vitrimers were synthesized using aldehydes and amines. Carbon fiber-reinforced composites were then manufactured using the vitrimer matrix. The repairability of these composites was assessed by subjecting them to temperatures above 100°C, which demonstrated that minor damages could be repaired through the application of heat and pressure.

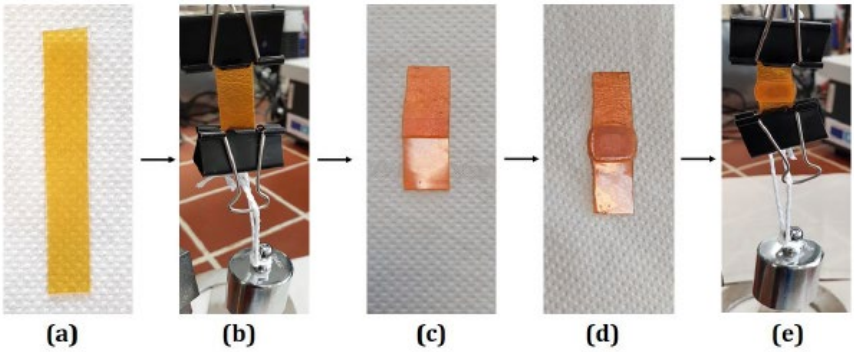

Figure 1: Lap shear test for (a) Vitrimer, (b) Vitrimer bearing 200 g weight, (c) Vitirmer with manual cut, (d) cured at 90 °C, (e) self healed vitrimer bearing 200 g weight.
Source: own.

The fibers were extracted from the composites by dissolving the vitrimer matrix, and new composites were created using the recycled fibers. Initial test results indicated that there were no significant changes in the mechanical strengths of the composites after recycling. An added advantage is that the extracted vitrimer matrix can be reused in the production of new composites by simply adding the stoichiometric ratio of monomers. Furthermore, within the Horizon Project ESTELLA, there is ongoing research into the development of renewable composites using natural fiber reinforcement. This presentation will provide an overview of the Horizon project and the preliminary results in the project.

Keywords: recyclabe composite, vitrimer, repairable,

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Preparation of Carboxy-Methyl-Dextran Coated Magnetic-Based Nanoparticles and Their Ability to Adsorb Ciprofloxacin

OLIVIJA PLOHL, MAŠA VRAČEVIČ, SAŠO GYERGYEK, TJAŠA KRAŠEVAC GLASER, MATEJ BRAČIČ, SILVO HRIBERNIK, ALENKA VESEL, LIDIJA FRAS ZEMLJIČ

The increase in antimicrobial resistance, also due to the release of antibiotics, has been identified as one of the most worrisome public problems of the present time. Therefore, electrochemical sensors modified with precisely and controllably designed nanomaterials that can improve the determination of antibiotics in contaminated environments are of particular importance. So far, many nanomaterials have been investigated, which not only have higher sensitivity but also have unique functions and enable the development of new analytical systems. However, conventional electrode surfaces have been mainly modified with nanomaterials such as graphene, carbon nanotubes, metals, conductive polymers, etc. (Jain, Jadon, and Pawaiya 2017; Asadian, Ghalkhani, and Shahrokhian 2019). The expensive synthesis routes, difficult removal of metal catalyst, hydrophobicity, agglomeration problems, and generated defects of nanomaterials make these nanomaterials not very promising for the design of highly efficient modified electrochemical sensors. In contrast, the use of magnetic NPs (MNPs) with controlled synthesis conditions and further functionalization with biopolymers

offers several advantages, such as large surface area, good electron conductivity, and more electroactive interaction sites, yet there is a large gap in this research area. Therefore, the aim of this work was to prepare magnetic iron oxide nanoparticles (MNPs) functionalized with polysaccharides having a set of functional target groups for selected antibiotics to improve the adsorption process, which subsequently leads to improved electrochemical sensing. MNPs were synthesized by co-precipitation and then coated with an approximately 2 nm thick porous silica (SiO_2; abbreviated S) layer to increase the effective specific surface area, and then functionalized with aminopropyl-triethoxysilane (APS; abbreviated A) to introduce -NH_2 groups. Then, the biopolymer carboxy-methyl-dextran (CMD) was electrostatically attached to MNPs@S@A. The obtained nanocomposite was characterized by transmission electron microscopy (TEM) to determine its morphology, size and the success of silica coating. The crystal structure was verified by X-ray diffraction (XRD). Each step of MNP modification was followed with infrared spectroscopy, electrokinetic measurements of the zeta potential, and X-ray photoelectron spectroscopy (XPS). Thermogravimetric measurements and magnetic properties were also checked. Then, the carefully fabricated nanocomposite was tested for the adsorption ability of ciprofloxacin at UV-VIS to verify the favourable adsorption for further evaluation as a successful modifier for electrochemical sensors. The results showed that all layers were successfully formed on the MNPs with the final CMD layer having functional groups for effective problematic ciprofloxacin adsorption and thus promising application as a modifier for effective electrochemical sensor.

Keywords: magnetic nanoparticles, carboxy-methyl dextran, ciprofloxacin, adsorption, electrochemical sensor

References

Asadian, Elham, Masoumeh Ghalkhani, and Saeed Shahrokhian, 2019, Electrochemical Sensing Based on Carbon Nanoparticles: A Review, Sensors and Actuators, B: Chemical, 293, 183–209.

Jain, Rajeev, Nimisha Jadon, and Archana Pawaiya. 2017, Polypyrrole Based next Generation Electrochemical Sensors and Biosensors: A Review, TrAC - Trends in Analytical Chemistry, 97, 363–73.

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Improved Hydrophobicity of Textiles by Increased Surface Roughness

ANJA VERBIČ, PETRA JERIČ, BLAŽ LIKOZAR, UROŠ NOVAK

Per- and polyfluoroalkyl substances (PFAS) have in recent years gained significant attention due to their widespread use, chemical stability, persistence and resistance to degradation, and consequently mostly adverse effects on human health and the environment. Over the past decades, the exceptional hydrophobic properties of PFAS have led to their extensive use in various industries, including textiles. As their toxicological properties have raised concerns (Fenton et al., 2021), an increased interest in developing materials with water-repellent properties in a more sustainable, responsible and non-toxic way also appeared. Two main factors influencing the hydrophobicity of the material are the surface morphology and the chemical composition. Most commonly, hydrophobic surfaces are prepared by a combination of surface roughening and lowering the surface energy (Kijlstra et al., 2002). Increasing the surface roughness of a textile material results in an increase of surface area. With increased roughness and surface area, more air is entrapped between the material and a water droplet, contributing to a higher water contact angle (WCA). This enables the textile material to have improved water-repellent properties, making them suitable for applications where water resistance, stain resistance or fast drying are desired. One of the ways to increase the surface roughness of the textile material is by functionalization with nanoparticles (Rivero et al., 2015). Due to their size, nanoparticles have a high surface area, which can be exploited to impart hydrophobic properties. They can be incorporated into a coating or applied using a binder and a spraying or dipping process. Furthermore, additional functionalities of

the textile can be achieved based on the properties of the selected nanoparticles. Zinc oxide (ZnO) nanoparticles have attracted considerable attention in various industries due to their multifunctional properties. When applied to textiles, they can provide UV-protective, antimicrobial, self-cleaning and other properties (Verbič et al., 2019), making them suitable for a wide range of applications. The influence of the modified surface morphology achieved with ZnO application on the wetting behaviour of textile substrates has also been investigated. Our study presents an attempt to replace the harmful PFAS textile coatings with ecologically acceptable alternatives. Cotton and polyester fabrics were coated using a layer-by-layer knife method with a biopolymer based coating with the addition of ZnO. WCA analysis was performed on the untreated and coated textile samples to determine the influence of incorporating ZnO nanoparticles on the wetting behaviour of the coated textiles.

Keywords: hydrophobicity, textile, surface roughness, flourine-free coating, biopolymers, zinc oxide

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References

Fenton S. E., Ducatman A., Boobis, A., DeWitt J. C., Lau C., Ng C., Smith J. S. and Roberts S. M., 2021. Per-and polyfluoroalkyl substance toxicity and human health review: Current state of knowledge and strategies for informing future research, Environmental toxicology and chemistry, 40, 606-630.

Kijlstra J., Reihs K., and Klamt A., 2002, Roughness and topology of ultra-hydrophobic surfaces, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 206, 521-529.

Rivero P. J., Urrutia A., Goicoechea J., and Arregui F. J., 2015. Nanomaterials for functional textiles and fibers, Nanoscale research letters, 10, 1-22.

Verbič A., Gorjanc M., and Simončič B., 2019. Zinc oxide for functional textile coatings: Recent advances, Coatings, 9, 550.

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6TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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A Computer-Aided Approach to Optimizing Spray Drying Operating Parameters

TINE PIGAC, AMANDA ŽIŽEK, DAVID TIAN HREN, MARKO PAVLOVIČ, URBAN KOLER, ANJA ZIRDUM, MIHA BERK BEVC, MATEJ KEBER, ŽAN ZORE, MILOŠ BOGATAJ

Spray drying in the food industry represents a great potential for various products and applications (Samborska et al., 2022, Yang et al., 2024) that has not yet been fully exploited. The problem is that spray drying is an energy-intensive process (Atuonwu and Stapley, 2017), requiring large flows of air, which must be heated up to 200 °C and dehumidified to remove excess moisture. At the same time, with inappropriate control, the system is also very sensitive to weather conditions. In addition to the flow rate and moisture content of the air supplied to the spray dryer, operating efficiency is affected by many properties of the feed solution (Homayoonfal et al, 2022). A high water content requires more energy and time for complete evaporation, which affects drying efficiency and overall process efficiency. The viscosity of the feed solution affects atomization and spray properties. Atomization is also affected by solids content. Particle size and distribution affect drying rate, heat and mass transfer properties, and physical properties of the final product. The heat capacity of the feed solution determines the amount of energy required to heat and evaporate moisture during drying, etc.

In a study, we attempted to determine the optimal operating conditions of a spray dryer. First, the thermodynamic and physical properties of the feed solution were analyzed using Aspen Plus software. It was assumed that the feed solution is a mixture of dry matter (mixture of sugars) and water. Simplified mathematical models were developed to predict key properties such as solubility, density, viscosity and enthalpy of evaporation, heat capacity, as a function of temperature and concentration of dry matter in the feed solution. We then developed dehumidification models in the Aspen Plus simulator based on the principles of condensation drying or desiccant drying. In the final phase of simulation model development, we developed a simulation model representing the complete dehumidification process, i.e., drying and heating of the supply air by a spray dryer and waste heat recovery.

We have assumed that the feed solution is an aqueous solution with a mass fraction ranging from 15 % to 45 %. The air used for drying is partially saturated with water vapor. It is dried to a content of 4 g H_2O per 1 kg of air. The dimensions of the spray dryer used were $d = 3$ m and $h = 6$ m. The heat transfer coefficient to determine the heat losses to the environment was estimated to be 12 W/(m^{2}K). The atomizer used was a rotary atomizer with a diameter of 0.15 m and a wheel speed of 15,000 min^{-1}. Under the given assumptions, it was found that the minimum operating cost per kg of product was achieved at a dry matter content of 30 %, an air flow rate of 12,570 kg/h, and an inlet air temperature of 182 °C. Heat recovery is critical to the energy efficiency of the spray drying process, as it can reduce energy demand by up to 40 %.

Keywords: spray drying, energy efficiency, process simulation, process optimization, process system engineering

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References

Atuonwu, J., Stapley, A., 2017, Reducing energy consumption in spray drying by monodisperse droplet generation: modelling and simulation. Energy Procedia, 123, 235–242. https://doi.org/10.1016/j.egypro.2017.07.251

Homayoonfal, M., Malekjani, N., Baeghbali, V., Ansarifar, E., Hedayati, S. M., Jafari, S. M., 2022, Optimization of spray drying process parameters for the food bioactive ingredients. Critical Reviews in Food Science and Nutrition, 1–41. https://doi.org/10.1080/10408398.2022.2156976

Samborska, K., Poozesh, S., Barańska, A., Sobulska, M., Jedlińska, A., Arpagaus, C., Malekjani, N., Jafari, S. M., 2022, Innovations in spray drying process for food and pharma industries. Journal of Food Engineering, 321, 110960. https://doi.org/10.1016/j.jfoodeng.2022.110960

Yang, D., Liu, R., Wei, Y., Sun, Q., Wang, J., 2024,. Micro-sized nanoaggregates: Spray-drying-assisted fabrication and applications. Particuology, 85, 22–48. https://doi.org/10.1016/j.partic.2023.03.013

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Current State and Possibilities for Recovery of Raw Materials From Sewage Sludge and its Recycling in Construction Composites

PRIMOŽ OPRČKAL, ANA MLADENOVIČ, ALENKA MAUKO PRANJIĆ,
MIHA ŠTRUC, JASNA SMOLAR

Management of sewage sludge represents a significant environmental and socio-economic problem, which is expected to grow in the future. In Slovenia, there are no systematic solutions for handling sludge, which is highly restricted from legislative, environmental, and technical perspectives. Successful approaches to managing sewage sludge should prioritize economically viable and sustainable processing of large quantities of sludge with minimal greenhouse gas emissions, while extracting valuable substances like phosphorus, nitrogen, and organic matter through environmentally and economically acceptable methods such as bioleaching. The remains after extraction can be used in construction, offering potential to replace natural resources like clay.

In Slovenia, daily sludge production amounts to 15-60 grams of dry solids per population equivalent (PE) with an annual production of approximately 38,000 tons. In the EU, the yearly dry solids production is between 9.5 and 10 million tons. As wastewater treatment requirements increase, sludge production is expected to rise further.

The general challenges in sludge management arise due to its classification as non-hazardous waste and environmental regulations, restricting disposal and incineration. For example, in the EU, 45% of sludge is used in agriculture without prior removal of potentially hazardous substances, leading to soil contamination. In Slovenia, sludge management has relied on export and incineration, but geopolitical factors have reduced options and increased costs, creating a financial burden for wastewater treatment plant operators.

Sustainable sludge management involves cascade recycling, focusing on extracting critical and other valuable substances, such as phosphorus. Phosphorus, essential for fertilizer production, is considered a critical resource in the EU and can be extracted from sludge using various methods, including bioleaching. Bioleaching is an environmentally friendly and economically efficient technology that uses bacteria to extract toxic elements or important resources from sludge. The process is based on direct bacterial action and indirect effects induced by low pH and redox potential changes. Compared to chemical leaching, bioleaching offers higher extraction yields but requires longer processing time. Additionally, it promotes the biodegradation of organic pollutants in sludge. Bioleaching represents a potential solution for extracting phosphorus from sludge, either directly or from the ash after incineration.

Material processing offers a promising avenue for recycling sludge and remaider of sludge after extraction of phosphorus into construction products. Treated sludge can be used as a secondary raw material for making bricks, ceramics, lightweight aggregates, and geotechnical composites for embankments or fills. Geotechnical composites are prepared by adding suitable binders to stabilize potentially hazardous substances. The use of calcareous-based ashes as binders enables the immobilization of hazardous elements due to the alkaline pH. Geotechnical composites exhibit mechanical strength, long-term stability, and low permeability, making them suitable for various less demanding earthworks. This approach allows for the use of locally available recycled materials, including large amounts of sludge.

In conclusion, addressing the challenges of sewage sludge requires developing sustainable material recycling methods that align with EU's Circular Economy Action Plan. Sludge-derived materials need to attain non-waste status to be used in construction products, and appropriate regulations for registering phosphorus fertilizers derived from sludge extraction should be established.

Keywords: Sewage sludge, phosphorus, construction composite, recycling, bioleaching.

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References

The references should be listed in alphabetical order:

ARSO, „Kazalci okolja - [OD08] Blato iz komunalnih čistilnih naprav,“: http://kazalci.arso.gov.si/sl/content/blato-iz-komunalnih-cistilnih-naprav-1.

Slovensko društvo za zaščito voda - Delovna skupina za reševanje blata iz ČN v okviru SDVZ, „Poročilo: Količina nastalega komunalnega blata v letu 2019,“ Ljubljana, 2019.

Inglezakis, Vassilis, Zorpas, Antonis, Karagiannidis, Avraam, Samaras, Petros, Voukkali, Irene, Sklari, Stella, „European Union legislation on sewage sludge management. Fresenius Environmental Bulletin. 23. 635-639.,“ Fresenius Environmental Bulletin, 23, pp. 635 - 639, 2014.

Mladenovič, A., Hamler, S., Zupančič, N., „Environmental characterisation of sewage sludge/paper ash-based composites in relation to their possible use in civil engineering,“ *Environmental Science and Pollution Research,* 24, pp. 1030 - 1041, 2016.

Bohan Y., Jinghuan L., Huanhuan X., Huan Y., Shanping C., Jianyong L., Ruina Z., Yu-You L., „Species, fractions, and characterization of phosphorus in sewage sludge: A critical review from the perspective of recovery,“ *Science of The Total Environment,* 786, p. 147437, 2021.

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6TH INTERNATIONAL CONFERENCE ON TECHNOLOGIES & BUSINESS MODELS FOR CIRCULAR ECONOMY:
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Use of Respirometry for Testing the Biodegradability of Cotton Pads and Tampons in the Presence of Blood

LIDIJA TUŠEK, VIKTORIJA ŠEGA, MATEJKA TUREL, ANDREJ HOLOBAR, ANDREJ ZABRET, LIDIJA FRAS ZEMLJIČ

Each woman utilizes thousands of hygiene products such as pads and tampons throughout her lifetime. With nearly 4 billion women in the world, this leads to a substantial amount of waste generated by these hygiene products. Consequently, it is crucial that this waste is composed of biodegradable materials to minimize its impact on the environment. The first step towards environmentally friendlier consumer behaviour is the use of organic materials such as cotton, linen, hemp, and similar fibres.

In this study widely available, commercial hygiene pads and tampons made of organic cotton by Slovenian producer were tested for biodegradability using ECHO 12-channel respirometer following the standard method for determination of aerobic biodegradability under controlled composting conditions ISO 14855-1:2012. To simulate as much as possible real degradation conditions of waste pads and tampons, we also added (a) physiological solution and (b) pig blood to the samples of pads and tampons and test them in the respirometer for 90 days.

The results demonstrated that the composition of hygiene products made from the same material greatly affects their biodegradability. Tampons exhibited higher biodegradability compared to multi-layered pads, with a rate of 74.9% versus 36.9%

after 90 days. Although the addition of physiological solution showed to have minimal impact on the biodegradability of hygiene products, the addition of blood contributed to higher biodegradability rates. In the case of tampons, the biodegradation rate reaches up to 97.3%, while for pads, it reaches 55.8%. These results can be partially attributed to the contribution of blood degradation, particularly fats and proteins, which lead to higher CO_2 production in the respirometer. Additionally, the effect of blood acting as a nutrient for microorganisms may also play a role.

Keywords: hygiene products, organic cotton, tampons, pads, biodegradability, respirometry, physiological solution, blood

References

ISO, 2022, ISO 14855-1:2012 Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions — Method by analysis of evolved carbon dioxide — Part 1: General method, <https://www.iso.org/standard/57902.html> accessed 13 June 2023.

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Magnetic Field as a Tool for Enhancing β-Lactamase Activity

KATJA VASIĆ, MATEJA PRIMOŽIČ , MISLAV TRBUŠIĆ, VIKTOR GORIČAN, MARKO JESENIK, ANTON HAMLER, ŽELJKO KNEZ, YILMAZ YÜREKLI, MAJA LEITGEB

Introduction: ß-Lactam antibiotics are the most common drugs used in bacterial therapy since the discovery of penicillin. Despite the enormous quantity of antibiotics in pharmaceutical industry available nowadays, bacteria usually develop defense mechanisms. The expression of ß-lactam degrading enzymes, β-lactamases, is the most common mechanism of antibiotic resistance among bacteria. Moreover, ß-lactam antibiotics are also toxic with only 20% degradability. Therefore, effective remediation of ß-lactam antibiotics is one of the most important requirements to prevent antibiotic pollution (Bhattacharya and Khare, 2022; Fan et al., 2022; Wasak et al., 2019).

Methods: Effect of treatment with sinusoidal and constant magnetic field (50 mHz frequency) was investigated on the activity of enzyme β-lactamase. The activity of β-lactamase was investigated in powder and solution form, while the effect of exposed time (2, 10, 15, 20, 30 and 60 min) was studied, as well. The circular dichroism (CD) spectra of free and treated β-lactamases were analyzed using a CD-spectrophotometer to determine the changes in secondary structures after magnetic field exposure of the enzyme.

Results: The effect of sinusoidal and constant magnetic field on the activity of β-lactamase in powder and solution form was analyzed, which revealed an enhanced activity of the treated enzyme, when compared to the non-exposed enzyme. The highest activity of treated enzyme in powder form under constant and sinusoidal magnetic field was achieved after 30 min and resulted in 128% and 174%, respectively. Additionally, secondary structures were determined via CD spectroscopy. The magnetic field treatment caused an alteration in the β-lactamase conformation. The % of α-helix were reduced while exposed in constant magnetic field (22%) and increased while exposed in sinusoidal magnetic field (33%), while compared to the non-exposed enzyme (28%). Additionally, the % of β-turn were reduced when exposed in constant magnetic field (32%) and increased when exposed in sinusoidal magnetic field (35%), while compared to the non-exposed enzyme (33%).

Conclusions: The concept based on applying the magnetic field to control the enzymatic activity of an enzyme seems to be a promising method for modifying the enzymes' catalytic performance. Our study showed that the β-lactamase activity can be modified by exposure to an external magnetic field by enhancing its enzymatic activity in a form of hyperactivation without any negative impact of the enzyme activity.

Keywords: β-lactamase, magnetic field, enzyme activity, hyperactivation, secundary structure

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References

Bhattacharya, A., Khare, S.K., 2022. Utilizing the ß-lactam hydrolyzing activity of ß-lactamase produced by Bacillus cereus EMB20 for remediation of ß-lactam antibiotics. International Biodeterioration & Biodegradation 168, 105363.

Fan, P., Ma, Z., Partow, A.J., Kim, M., Shoemaker, G.M., Tan, R., Tong, Z., Nelson, C.D., Jang, Y., Jeong, K.C., 2022. A novel combination therapy for multidrug resistant pathogens using chitosan nanoparticles loaded with β-lactam antibiotics and β-lactamase inhibitors. International Journal of Biological Macromolecules 195, 506–514.

Wasak, A., Drozd, R., Jankowiak, D., Rakoczy, R., 2019. Rotating magnetic field as tool for enhancing enzymes properties - laccase case study. Sci Rep 9, 3707.

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Waste Analysis and Determination of the Average Composition of Municipal Waste with a Focus on the Circular Economy

JIŘÍ GREGOR, JIŘÍ KROPÁČ, MARTIN PAVLAS, YEE VAN FAN

Waste treatment represents a significant challenge for society and the environment, and its effective management is essential to achieve a sustainable future. This paper focuses on the sorting, analysis and composition of waste in the context of the circular economy, with an emphasis on the established legislative aspects and separation goals in the European Union.

The European Union recognises the urgent need to change the linear model of production and consumption to a circular economy in which waste production is minimised, resources are used sparingly and the environment is protected. In order to achieve these objectives, the EU has adopted very ambitious legislation aimed at improving waste management overall.

In our paper we will focus on key legislative aspects. We will analyse how this legislation sets new targets and requirements for waste separation, introduces extended producer responsibility schemes and promotes recycling and resource recovery. We will also look at the monitoring and evaluation mechanisms that are in place to track progress and ensure compliance with these targets.

We will also present examples of best practices and innovative initiatives that already exist within the European Union that serve as inspiration for the transition to a circular economy. These examples may include new technologies for more efficient waste separation, sharing economy systems and resource recovery models.

As a result, we will present the implementation of the determination of the average composition of waste from the perspective of the Czech Republic and selected sub-regions. The main points of the new methodology will be presented, which are crucial for the comparability and especially the repeatability of the results. At the same time, basic findings from practical implementation will be presented. This paper will contribute to the discussion on practical aspects of the circular economy and will strengthen the awareness of the necessity of efficient waste management for a sustainable future.

Keywords: waste management, circular economy, the composition of waste, sampling, representative sample, new methodology, sorting analyses

References

Pavlas M., Šomplák R., Roupec J., Talpa J., Smejkalová V.; TiramisO - Prognóza produkce odpadů; Ministry of the environment of the Czech Repubplic; available on www.tiramiso.mzp.cz

Commission for Environmental Cooperation; Waste Composition Analysis; available on www.cec.org/flwm/method/waste-composition-analysis/

iC consulenten ZT GmbH, Methodology for the Analysis of Solid Waste (SWA-Tool) User Version, 2004; 5th Framework Program EU; Available on: https://www.wien.gv.at/meu/fdb/pdf/swa-tool-759-ma48.pdf

Dahlén L., Lagerkvist A., Methods for household waste composition studies; Waste Management 28(7), 2008. Available on: www.sciencedirect.com/science/article/pii/S0956053X0700270X#bbib1

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Visual and Numerical Presentation of Current State of the Energy System in Slovenia

DAVID HVALEC, FRANCO KROG, JURIJ AVSEC, MILOŠ BOGATAJ, ANDREJA NEMET

The aim of this work is to comprehensively present the current state of the energy system in Slovenia. Data were collected separately for each of the 212 municipalities. For each municipality, the installed capacity of existing renewable and fossil energy sources is presented. The following renewable energy sources were considered: Hydropower (small and large run-of-river and storage power plants), geothermal energy, wind energy, solar energy and photovoltaics, cogeneration by burning biogas and wood biomass. In the case of fossil fuels, power generation by cogeneration with various combustion engines and gas turbines with heat recovery was considered. Furthermore, the capacities of thermal power plants (TE Šoštanj, TE Trbovlje and TE Brestanica) and fossil energy and nuclear energy (Nuklearna elektrarna Krško) were taken into account. In the calculations, we also took into account waste heat in industry. The online portals Borzen and the Statistical Office of the Republic of Slovenia (SURS) as well as various local energy concepts and plans and the annual energy reports of the municipalities served as data sources. To validate the data, the sum of individual energy capacities was compared with the available data for total energy sources. The obtained totals by sum up were: 142.7 MW for wood biomass, 39.5 MW for biogas, 37.5 MW for geothermal energy, 3.3 MW for wind energy, 1235.6 MW for photovoltaic, 116.2 MW for fossil

cogeneration, 1308 MW for thermal power plants, 730 MW for nuclear energy and 3948.3 MW for total capacity. These data were compared to hydro, solar, and wind capacities with existing capacity data from the Office of National Statistics. The comparison resulted in a data coverage of 91.3% for hydro, 61% for solar, and 100% for wind. With the help of the Statistical Office, we also obtained data on electricity consumption by households and businesses in each municipality. We presented the result as the average monthly energy consumption of households and industries for the year 2022. The average monthly electricity consumption of households in 2022 was 2.91 TWh and that of businesses was 6.38 TWh. The obtained results are presented in a geographic information system (GIS) on the map of Slovenia with the program Anylogic. This work serves as a first step for further evaluation of the whole energy system in Slovenia, considering options for cross-sector integration using different energy sources.

Keywords: energy system in Slovenia, energy sources, Anylogic, GIS

References

Borzen, 2023, Atlas trajnostne energije, < https://borzen.maps.arcgis.com/apps/webappviewer/index.html?id=9a8d05acccff4a908f66de6958c9a3bc> accessed 12. June 2023

SURS, 2023, Poraba električne energije (kWh) po vrsti odjemalca, občine, Slovenija, mesečno < https://pxweb.stat.si/SiStatData/pxweb/sl/Data/Data/1817607S.px/> sccessed 12. June 2023

SURS, 2023, Proizvodnja in dejanska moč v elektrarnah - glavna dejavnost, samoproizvajalci in male zasebne hidroelektrare, Slovenija, letno, < https://pxweb.stat.si/SiStatData/pxweb/sl/Data/-/1817604S.px> accessed 12. June 2023

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Using Eco-Friendly Solvents to Extract Limonene from Orange Peel Waste

MONIKA OGRIZEK, FILIPA A. VICENTE, KRISTINA ANDREJC, BLAŽ LIKOZAR

Limonene is a terpene with a strong orange aroma that is present in many consumable products. It is widely used in food and cosmetic industries due to its desired flavor and fragrance, as well as antimicrobial and other health benefit properties, which are also exploited for medicinal use. Limonene is naturally present in citrus fruits, especially in orange peels, where limonene represents more than 90 % of the essential oils. Tens of millions of tons of citrus waste are annually produced during the manufacturing of juice and other products, which is problematic for composting. On the other hand, it is an unexploited source of limonene that holds high potential (Siddiqui, Pahmeyer, Assadpour, & Jafari, 2022). Due to its strong hydrophobic nature, limonene is conventionally extracted with organic solvents, which are often not biodegradable and are toxic to the environment. Eutectic solvents have recently started to being explored as an alternative to organic solvents in biomass extraction (Vicente et al., 2022), mainly because it is possible to tailor-make the solvent. Hence, specific solvent properties can be designed for the best extraction yield of the targeted analyte and minimal extraction of the impurities. Furthermore, the eutectic solvents are normally designed to be biodegradable and nontoxic, and thus have less burden on the environment. Due to those positive properties, the eutectic solvents can also have other application benefits, besides the

solution capabilities, such as increased stability of the extracted analyte or the elimination of purification steps if the eutectic solvent could be present in the final product.

Therefore, our work aims to design an eutectic solvent, which could be directly applied to cosmetic products and would have high extraction yields of limonene extracted from orange peels. In the beginning, we evaluated the conventional approach by optimizing extraction procedures for four organic solvents using solid-liquid extraction (SLE) and Soxhlet extraction. The limonene was determined by GC-MS analysis and the total protein concentration was determined by UV/VIS spectroscopy. During the search for the optimal eutectic solvent, many different combinations were tested, out of which we selected the ones *i)* containing constituents nontoxic for human skin, *ii)* that are hydrophobic enough for dissolving the limonene, *iii)* that are fluid at the extraction temperature, and *iv)* enable liquid-liquid extraction of limonene with organic solvents, which is needed merely for analytical determination of its concentration. Out of the tested organic solvents, we identified the one with the highest extraction yield of limonene with SLE. We also identified 8 suitable eutectic solvents which have potential for the limonene extraction from orange peels.

Keywords: limonene, orange peel, eutectic solvents, organic solvents, solid-liquid extraction

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References

Siddiqui S. A., Pahmeyer M. J., Assadpour E., Jafari S. M, 2022, Extraction and purification of d-limonene from orange peel wastes: Recent advances, Industrial Crops and Products, 177, 114484.

Vicente F. A., Ventura S. P. M., Passos H., Dias A. C. R. V., Torres-Acosta M. A., Novak U., Likozar B, 2022, Crustacean waste biorefinery as a sustainable cost-effective business model, Chemical Engineering Journal, 442, 135937.

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Hydrogels Based on Nanofibrillated Cellulose

IDA POLJANŠEK, URŠA OSOLNIK, VILJEM VEK, PRIMOŽ OVEN

Hydrogels are 3D network systems known for their exceptional water retention, shape retention, and dimensional stability. Among various materials for bioactive hydrogel preparation, nanofibrillated cellulose (NFC) stands out due to its natural origin and possible applications in medicine. NFC is derived from cellulose, the primary component of plant cell walls, by reducing cellulose fibriles to nanoscale dimensions. This process gives NFC unique properties that make it highly suitable for hydrogel applications with excellent mechanical, chemical, and biological characteristics. NFC hydrogels exhibit remarkable biocompatibility, allowing safe interactions with biological systems, they can absorb and retain significant amounts of water, mimicking the hydrated environment in biological tissues. They have gained attention for biomedical applications like drug delivery, tissue engineering, as scaffolds for cellular growth and wound dressings for healing.

The properties of NFC hydrogels can be customized by adjusting NFC nanofiber concentration, cross-linking degree, or incorporating additives. This tunability allows researchers to tailor the hydrogel's characteristics to specific application requirements. Additionally, NFC is derived from renewable resources like wood pulp, making it an environmentally friendly material. NFC hydrogel production contributes to sustainable material utilization and reduces reliance on non-renewable resources. This presentation provides an overview of NFC hydrogel production,

emphasizing their potential for developing innovative and sustainable solutions across various applications.

Keywords: hydrogels, nanofibrillated cellulose, biocompatibility, sustainability, drug delivery, tissue engineering

References

Žepič Bogataj, V., P. Oven, M. Čop, V. Vek, B. Janković, and I. Poljanšek. Physical, rheological and mechanical properties of alkali activated hydrogels based on nanofibrillated cellulose. *Journal of natural fibers*, 2022, 19 (17), 16040-16052.

Levanič, J., I. Poljanšek, V. Vek, M. Narat, and P. Oven. Chlorhexidine digluconate uptake and release from alkane-crosslinked nanocellulose hydrogels and subsequent antimicrobial effect." *Bioresources,* 2020a, 15 (2), 3458-3472.

Levanič, J., M. Gericke, T. Heinze, I. Poljanšek, and P. Oven. Stable nanocellulose gels prepared by crosslinking of surface charged cellulose nanofibrils with di- and triiodoalkanes. *Cellulose,* 2020b, 27(4), 2053-2068.

Abe, K., and H. Yano. Formation of hydrogels from cellulose nanofibers. *Carbohydrate Polymers,* 2011, 85, 733–737.

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RESHeat: GHG Emission Reduction and Increased Energy Security by Supporting Urban and Rural Prosumers

PETAR SABEV VARBANOV, PAWEŁ OCŁOŃ, TING PAN,
ZDRAVKO KRAVANJA, ANDREJA NEMET

It has been reasoned by the authors of this work that the application of the combined power and heat generation for buildings using the RESHeat system contributes simultaneously to GHG emission reduction due to the use of solar energy and to the increase of the security of energy supply due to the use of local generation. A recent collaboration of the Brno University of Technology and the Cracow University of Technology has evaluated the potential for local power generation in an experimental housing estate to satisfy the energy needs from only PV power generation. It was shown that the roof area could be made sufficient to install a highly oversized PV array capable of generating enough power even in the winter period. However, this resulted in an estimated annual excess of PV generation capacity of nearly 8 MWh/y per house. If stored in the summer and then reused in the winter, the excess capacity can be used to either sell the extra power to the market or to reduce the oversizing of the PV arrays.

This work takes the initial RESHeat system setup of heat storage and ground heat regeneration, using PV, PVT and solar thermal capture, as a departure point. It evaluates the preliminary technical and economic feasibility of potentially installing electricity storages of several types and at several scales to provide increased energy security and reduced GHG emissions at minimal oversizing of the solar panels (PV, PVT, solar thermal).

Keywords: RESHeat system, GHG emission, solar panels, heat storage

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The Influence of Different Operation Atmospheres on the Produced Biochar Quality

MARJANA SIMONIČ, CHRISTOPH HOCHENAUER, NIKA FEKONJA, DARKO GORIČANEC, DANIJELA URBANCL

Biological wastewater treatment plants are used for water purification, but on the other hand, they generate large amounts of sewage sludge and other solid residues. Sewage sludge and the residues on screens have promising energy content (Petrovič et al. 2023). The research deals with the characterization of two different samples from small wastewater treatment plant, the dewatered sewage sludge and the material remaining on a fine screen after the removal of sand particles and mineral oils. The added value of the waste produced is application of the torrefaction process. The process of torrefaction is one of the thermo-chemical conversion routes that improves the properties of the feed stock, eliminates pathogenic organisms and produces an ecologically acceptable energy source with similar properties to coal (Ivanovski et al. 2022). To establish torrefaction, a pilot process was developed in which various waste materials were processed and the effects of different process parameters, such as the influence of different atmospheres and temperatures (Simonič et al. 2020) on the quality of the biofuel, were studied. The raw samples and the solid products of thermal treatment were analyzed by comparing the energy efficiency, mass drop, mass yields, high heating values and energy yields.

Keywords: torrefaction, CO_2 atmosphere, N_2 atmosphere, biofuel

References

Ivanovski M., Goričanec D., Krope J., Urbancl D., 2022, Torrefaction pretreatment of lignocellulosic biomass for sustainable solid biofuel production. Energy. 240, DOI: 10.1016/j.energy.2021.122483

Petrovič A., Stergar J., Škodič L., Rašl N., Cenčič, T., Čuček L., Goričanec D., Urbancl D., 2023, Thermo-kinetic analysis of pyrolysis of thermally pre-treated sewage sludge from the food industry, Thermal science and engineering progress, 42, DOI: 10.1016/j.tsep.2023.101863.

Simonič M., Goričanec D., Urbancl D., 2020, Impact of torrefaction on biomass properties depending on temperature and operation time, Science of the total environment, 740, DOI: 10.1016/j.scitotenv.2020.140086

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Future Proof Plastics, Closing the Carbon Loop

JAAP VENTE, PIETER IMHOF

In the chemicals industry, polymers are the biggest product group and have a major impact on environment by e.g. CO_2 and emissions. In order to meet the CO_2 reduction and sustainability targets, a significant effort must be made to make plastics proof.

In this presentation an overview will be given on the various approaches to make plastics future proof. The 4 main approaches are Narrowing the loop, Operating the loop, Slowing the Loop and Closing the Loop. These elements towards transition to future proof plastics transition require actions in legislation & policy, circular chain collaboration, design & development, as well as in Information & education. Examples will be given how TNO enables this transition with technologies and systems integration.

Keywords: renewable materials, material transition, systems integration, energy transition, plastics

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Innovative Technologies for Critical Raw Materials Extraction from WEEE

DRAGICA MARINIČ, MIHA ŠTRUC, PRIMOŽ OPRČKAL,
ALENKA MAUKO PRANJIĆ, MATEJA KOŠIR

Rapid population and economic growth with changed consumers patterns as well as dependence of modern society on the increasing use of information and communication technology and use of electrical and electronic devices significantly increase quantities of Waste from Electrical and Electronic Equipment (WEEE) (Graedel et al., 2013). The EU produces 4.7 million tonnes of WEEE annually (Destatis, 2023) and it represents the fastest growing waste stream in the EU where less than 40% of it is recycled (EP, 2022). This type of waste contains materials can pollute the environment and cause hazards to human health. At the same time WEEE represents an important secondary source of critical raw materials (CRM), including rare earth elements (REE). To prevent WEEE production and to reduce its quantity the EU has adopted several measures in the frame of the Circular Economy Action Plan (EC EU, 2020) and the Green Deal (EC EU, 2019). The EU imports almost 98% of REE and 44% of other critical raw materials (CRM) for the needs of various economic sectors. Therefore, it is necessary to develop and test innovative technologies for extraction of CRM out of WEEE. Such techniques successfully contribute to reducing the carbon footprint of WEEE management and enable extraction of light and heavy REE, platinum group, Mg, Ga, Sr, Li, Ni, Cu, Al, Fe and other metals (Kaya, 2018; Charles et al, 2020; Ji et al, 2022).

The main objective of the EIT RawMaterials project WEEE-NET9, is to untap novel solutions in Eastern and Southeastern Europe for obtaining CRM from WEEE through introduction of new WEEE processing technologies and the establishment of a comprehensive WEEE processing value chain. This will lead to modular WEEE recycling process that includes the selective collection of various WEEE (e.g., printed circuit boards, mobile phones and washing machine electric motors), their pre-processing in the form of cleaning, dismantling, crushing and milling, and recycling using an innovative method such as gravity and magnetic separation, followed by biological leaching using heterotrophic and autotrophic bacteria and/or electrochemical leaching. These can also be combined, if necessary, with pyrometallurgical extraction of CRM. The results of the project, in addition to bringing the multi-phase process closer to the market, will also be an analysis of the economic efficiency of the technologies used; new technological knowledge on WEEE recycling of all actors in the value chain, development of new circular business models, reduction of energy consumption, costs and carbon footprint as well as established synergies with existing local, regional and national innovation ecosystems of waste management. It is expected that based on knowledge gather, partners can contribute to the design of appropriate legislative support and other EU measures (EP, 2023) in the direction of a circular economy with smart consumption and sustainable production, which will contribute to reducing the amount of WEEE and the carbon footprint. The continued implementation of innovative technologies for the extraction of CRM from WEEE namely illustrates the added value for all participants in the WEEE recycling value chain and increase their business efficiency as well as to European and global society.

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References

Charles, R.G., Douglas, P., Dowling, M., Liversage, G., Davies, M.L., 2020, Towards Increased Recovery of Critical Raw Materials from WEEE– evaluation of CRMs at a component level and pre-processing methods for interface optimisation with recovery processes, Resources, Conservation and Recycling

Volume 161, October 2020, 104923, https://doi.org/10.1016/j.resconrec.2020.104923.

Destatis 2023, Europe in figures

<https://www.destatis.de/Europa/EN/Topic/Environment-energy/E_Waste.html> accessed 18 July 2023.

EC EU, European Commission, The European Green Deal, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and social Committee and the Committee of the Regions, COM 640 final, 2019.

EC EU, European Commission, A new Circular Economy Action Plan For a cleaner and more competitive Europe, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and social Committee and the Committee of the Regions, COM 98 final, 2020.

EP, European Parliament, 2023, Critical raw materials act,
<https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/747898/EPRS_BRI(2023)747898_EN.pdf>
accessed 7 August 2023.

EP, European Parliament, 2022, E-odpadki v EU-podatki (infografika)
<https://www.europarl.europa.eu/news/sl/headlines/society/20201208STO93325/e-odpadki-v-eu-podatki-infografika?&at_campaign=20234>
accessed 17 July 2023.

Graedel, T.E., Harper, E.M., Nassar, N.T., Reck, B.K., 2013, On the materials basis of modern society, PNAS, 112 (2013), pp. 6295-6300,
<https://www.pnas.org/doi/full/10.1073/pnas.1312752110>
accessed 18 July 2023.

Ji, X., Yang, M., Wan, A., Yu, S., Yao, Z., 2022, Bioleaching of Typical Electronic Waste - Printed Circuit Boards (WPCBs): A Short Review. Int. J. Environ. Res. Public Health 2022, 19 (12), 7508, https://doi.org/10.3390/ijerph19127508.

Kaya M., 2018, Current WEEE recycling solutions, Waste Electrical and Electronic Equipment Recycling Aqueous Recovery Methods, Woodhead Publishing Series in Electronic and Optical Materials 2018, Pages 33-93, https://doi.org/10.1016/B978-0-08-102057-9.00003-2.

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Investigation of Artificial CO_2 and Fruit Syrup Addition on Fermentation Course of Kombucha Beverage

DARJA PEČAR, ANDREJA GORŠEK

Kombucha is a popular beverage among the many traditional fermented foods. The bacteria and yeasts present in the medium form a strong symbiosis that can inhibit the growth of contaminating microorganisms (Villareal-Soto, 2018). It consists of two phases: a floating biofilm and an acidic liquid phase. Under aerobic conditions, the symbiotic consortium of kombucha can convert sugars and tea into a slightly carbonated, slightly acidic and refreshing beverage consisting of several acids, 14 amino acids, vitamins and some hydrolytic enzymes in a period of 7 to 10 days (Malbaša et al., 2011). The conditions of the fermentation process have a significant impact on the bioactive compounds in kombucha in terms of their biological activities. In our research work, we studied the primary and secondary fermentation process of sweetened tea with kombucha. We investigated the effects of artificially added CO_2, fruit syrup, and temperature of the fermentation medium on the quality of the finished beverage. For this purpose, the concentration of sugar, CO_2, ethanol, and pH during fermentation were studied. We used high-performance liquid chromatography and ion-selective electrode to monitor the bioprocess parameters. The primary fermentation lasted one week and the secondary fermentation about one month. In general, we have confirmed that pH and sugar concentration decrease during the fermentation process, while CO_2 and ethanol concentrations increase. However, we have found that the addition of fruit syrup to kombucha accelerates

the process of secondary fermentation by producing a more acidic, carbonated beverage with a higher alcohol content in a shorter time. Therefore, the addition of syrup is useful if we want to make a sweeter drink with higher alcohol content and additional flavour. On the other hand, we have found that artificially added CO_2 inhibits fermentation at the beginning of the process (in the first 14 days). After that, the values gradually begin to decrease or increase, which is quite comparable to the course of natural secondary fermentation. Thus, we have confirmed that the artificially added CO_2 has no effect on the final kombucha product, since the product obtained by natural fermentation has the same quality.

The results also prove that temperature plays an important role in secondary fermentation. At a higher temperature (35 °C), fermentation proceeded faster, pH and sugar concentration decreased faster, while CO_2 and ethanol concentrations increased rapidly compared to the course of secondary fermentation at room temperature (24 °C). The opposite was observed when kombucha fermentation took place in a refrigerator (5 °C). Lower fermentation temperatures slowed down the process. Finally, we concluded that the fermentation process is strongly influenced by the starter culture used, its shape, size, origin and age. The quality of the finished beverage is comparable only when the experiments are performed with a kombucha of the same origin.

Keywords: kombucha, secondary fermentation, CO_2, ethanol, sugar

References

Malbaša R., Lončar E. S., Vitas J. S., Čanadanović-Brunet J. M., 2011, Influence of starter cultures on the antioxidant activity of Kombucha beverage, Food Chemistry, 127(4), 1727-1731.
Villarreal-Soto S. A., Beaufort S., Bouajila J., Souchard J., Taillandier P, 2018, Journal of Food Science, 83(3), 580-588.

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Towards a Circular Built Environment – Lessons from the Netherlands

ARJAN VAN TIMMEREN

Rapid urbanization and a growing world population has exerted unsustainable pressures on the environment, exacerbating climate change through unrestrained material usage and greenhouse gas (GHG) emissions. Since the turn of the century, transitioning to a circular economy (CE) has been seen by policy makers as a potential solution for resource scarcity and climate mitigation. A CE aims to keep materials and products performing at their highest performance level using strategies such as recycling, remanufacturing, and reuse. Cities, which possess a high density of human activities, material stock, and waste production, are major contributors to emissions. This is especially true due to the concentration of construction activities in cities – the industry is responsible for 38% of CO_2 emissions and 40% energy consumption globally. On the other hand, cities can also facilitate the implementation of circular strategies, thanks to increasing availability of data on space, people, and materials in cities. The transition to such an economy necessitates an understanding of the locations and scales material flows—an endeavour for which we are increasingly equipped due to the rapid digitalization of society. Through harnessing the vast amounts of data now available, we have an unprecedented opportunity to generate insights into our economies' spatial and material dimensions.

This contribution will focus on giving an insight in actual approaches in the Netherlands regarding the transition towards a 'Circular Built Environment (CBE)'; "a system designed for closing resource loops at different spatial-temporal levels by transitioning cultural, environmental, economic & social values towards a sustainable way of living (thus enabling society to live within the planetary boundaries)" (CBE-Hub TU Delft, 2023). In the Netherlands, through a government and nation-wide program a CE is aimed for to be reached by 2050. The ambition is to realise this with a variety of stakeholders, with an interim objective of realising a 50% reduction in the use of primary raw materials (minerals, fossils and metals) by 2030. It highlights economic opportunities because of the required transition, instead of emphasizing limitations, while also making the country less dependent on import of scarce raw materials and contributing to a cleaner environment. This contribution will focus on the built environment. It will do so too, through several recent (European) research projects in which aspects of this were studied, from the scope of the TU Delft CBE Hub. This includes a range of foci, or as the CDE Hub states it a 'scales to aspects' range. This implies starting from materials and components, the base ingredients of buildings, to buildings as assemblies of large amount of building products, materials and components, and how they relate to circular performance. One step up, neighborhood scale represents how circularity currently manifests in specific areas or districts. Cities' scale explores the most important resource flows that enter, circulate and leave the urban environment every day. Finally, regional scale refers to the characteristic of the urban (or: territorial) metabolism and the importance to investigate economic activities to identify the flows and stocks of materials, products and waste.

References

CBE Hub TU Delft https://www.tudelft.nl/en/architecture-and-the-built-environment/research/research-themes/circular-built-environment

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The 6th 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 6th to September 8th, 2023. The Netherlands joined us as a partner country of the conference. TBMCE 2023 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 2 round tables, 6 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. The event was under the patronage of Ministry of the Economy, Tourism and Sport and Ministry of Cohesion and Regional Development.

Ključne besede:
circular economy, sustainable development, processes and technologies, circular business models, research and development

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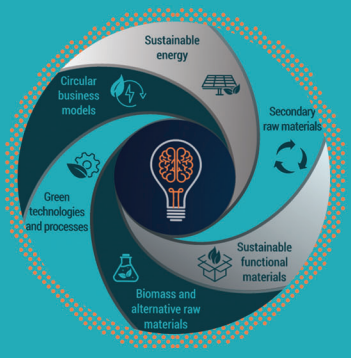

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